PB89-224794

Reduction of Solvent Wastes in the Electronics Industry. Waste Reduction Grant Program

Envirosphere Co., Santa Ana, CA

Prepared for:

California Dept. of Health Services, Sacramento

Jun 88

U.S. Department of Commerce
National Technical Information Service
NTIS

PB89-224794

FINAL REPORT

STATE OF CALIFORNIA Department of Health Services

Toxic Substances Control Division
Alternative Technology and Policy Development Section

The Reduction of Solvent Wastes in the Electronics Industry

Waste Reduction Grant Program

GRANT NUMBER 86-T0110
JUNE 1988

prepared by

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in cooperation with

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REPRODUCED BY
U.S. DEPARTMENT OF COMMERCE
NATIONAL TECHNICAL INFORMATION SERVICE
SPRINGFIELD, VA. 22161

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. 005-010 A	2.	3. Recipient's Accession No. PB89 224794/AS
4. Title and Subtitle The Reduction of Solvent Wastes in the Electronics Industry: Final Report			5. Report Date June 1988
			6.
7. Author(s)			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Envirosphere Company 3000 West MacArthur Boulevard Santa Ana, CA 92704			10. Project/Task/Work Unit No.
			11. Contract(C) or Grant(G) No. (C) (G) 86-T0110
12. Sponsoring Organization Name and Address California Department of Health Services Toxic Substances Control Division, Alternative Technology Section 714/744 P Street Sacramento, CA 95814			13. Type of Report & Period Covered
			14.

15. Supplementary Notes
This document is included in the Pollution Prevention Information Clearinghouse, operated by Science Applications International Corporation (SAIC) for the U.S. EPA, at 8400 Westpark Drive, McLean, Virginia 22102.

16. Abstract (Limit: 200 words)

The microelectronics component manufacturing processes at Hewlett Packard's San Jose facility were used as a model to study the techniques required to reduce the volume and type of organic solvent wastes in the electronics industry. Although organic solvent wastes are produced from numerous complex wafer fabrication steps, the volume and type of solvents utilized in each steps were documented and evaluated for waste reduction. This study indicates that up to a 70 percent reduction in organic solvent waste volume at the facility could be realized. This represents a potential cost savings to Hewlett Packard of up to $414,000 per year in disposal costs and chemical purchase costs.

The findings of this study indicate that 1) solvent segregation, 2) solvent substitution, 3) direct solvent reuse, and 4) distillation/evaporation are the primary solvent handling processes that could be utilized to accomplish this 70 percent solvent reduction.

17. Document Analysis a. Descriptors
pollution prevention, solvent wastereduction

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
Release unlimited		97
	20. Security Class (This Page)	22. Price

(See ANSI-Z39.18) See Instructions on Reverse OPTIONAL FORM 272 (4-77) (Formerly NTIS-35) Department of Commerce

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June 28, 1988

Mr. Frank Mele
Department of Health Services
Toxic Substances Control Division
Alternative Technology and Policy
Development Section
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SUBJECT: FINAL REPORT FOR GRANT NUMBER 86-T0110:
THE REDUCTION OF SOLVENT WASTES IN THE
ELECTRONICS INDUSTRY

Dear Mr. Mele:

Envirosphere Company in cooperation with Hewlett Packard Company is pleased to submit one (1) camera-ready copy plus eight (8) copies of our final report for the study of solvent waste reduction in the electronics industry. This project has represented another unique study opportunity because Hewlett Packard Company has made their full-scale manufacturing process available for investigation. Ms. Gail Brownell, Project Director and Environmental Engineer at Hewlett Packard's San Jose facility, acted as official liason with various manufacturing personnel so that each wafer fabrication process step producing solvent wastes could be evaluated. In many cases, Hewlett Packard personnel interrupted their normal work process to accommodate the conduct of our project.

This study indicates that up to 70 percent of the organic solvent waste volume at Hewlett Packard's San Jose facility can be potentially recycled. This waste reduction represents approximately 31,100 gallons per year that currently costs $93,000 per year to dispose of. More importantly, this waste reduction would save the purchased chemical cost of over $321,000 per year.

The Project Staff wishes to acknowledge the positive direction and management under your charge that we have received from the Department's Alternative Technology and Policy Development Section.

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Implementation of the findings of our study could potentially allow for the following:

- On-site recycling of solvents
- Substantial reduction of solvent wastes disposal volumes
- Commensurate cost savings from the reduced purchase of new solvents and the reduced volumes of solvent waste for disposal.

In conclusion, we feel that Envirosphere, Hewlett Packard, and the Department have worked well together. We look forward to working together again on the Step II Process Design project.

Sincerely,

Richard L. Jenkins, Ph.D, P.E.
Project Manager

DWH/mjo

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PROJECT ABSTRACT

The microelectronics component manufacturing processes at Hewlett Packard's San Jose facility were used as a model to study the techniques required to reduce the volume and type of organic solvent wastes in the electronics industry. Although organic solvent wastes are produced from numerous complex wafer fabrication steps, the volume and type of solvents utilized in each step were documented and evaluated for waste reduction. This study indicates that up to a 70 percent reduction in organic solvent waste volume at the facility could be realized. This represents a potential cost savings to Hewlett Packard of up to $414,000 per year in disposal costs and chemical purchase costs.

The findings of this study indicate that 1) solvent segregation, 2) solvent substitution, 3) direct solvent reuse, and 4) distillation/evaporation are the primary solvent handling processes that could be utilized to accomplish this 70 percent solvent reduction.

ACKNOWLEDGEMENTS

The Project Team would like to thank Mrs. Hazel Kelley, Ms. Gail Brownell and the Hewlett Packard wafer fabrication supervisors for their efforts in providing data and conducting extensive tours in order to identify the numerous and complex solvent generating chemical processes. Without their assistance and exhibited professionalism, our project schedule would have been seriously protracted.

This report was submitted in fulfillment of Grant Number 86-T0110 by Envirosphere Company under the sponsorship of the Department. Work was completed as of June 30, 1988.

DISCLAIMER

The statements and conclusions of this report are those of the Grantee and not necessarily those of the State of California. The mention of commercial products, their source, or their use in connection with material reported herein is not to be construed as either an actual or implied endorsement of such products.

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SUMMARY AND CONCLUSIONS

This project involved the review and evaluation of various chemical and physical processes capable of reducing the volume of organic solvent wastes in a manner that could be economically and environmentally justified to the microelectronics industry. The detailed study of the numerous complex wafer fabrication process steps at the Hewlett Packard San Jose facility revealed that all three (3) of the wafer fabrication areas produce much the same organic solvent wastes. These waste streams are amenable to various on-site recycling and process modification (source reduction) techniques that could reduce up to 70 percent of the solvent waste volume produced at this facility. Specific findings are listed below.

1. As much as 31,100 gallons per year of organic solvent waste may be reduced by implementation of on-site waste reduction techniques.

2. Approximately $93,000 per year may be saved in solvent waste disposal costs at HP's San Jose facility by implementing on-site waste reduction techniques.

3. At least $321,000 per year may be saved in solvent purchase costs if solvent usage can be reduced using on-site recycling/source reduction techniques.

4. The most viable on-site solvent waste reduction techniques are:

   - Solvent Segregation
   - Direct Reuse
   - Solvent Substitution (aqueous and organic)
   - Distillation/Evaporation

5. Eight (8) organic solvents have been selected as the most amenable to waste reduction techniques because they represent almost 87 percent of the San Jose facility total volume. These solvents are produced in all three (3) wafer fabrication areas - Microwave Semiconductor

RECOMMENDATIONS

1. Process design and evaluation is recommended for the four (4) following organic solvent waste reduction techniques:

   - Solvent Segregation
   - Direct Solvent Reuse
   - Solvent Substitution (aqueous and organic)
   - Distillation/Evaporation

2. The above waste reduction techniques should be performed for the following eight (8) organic solvents at Hewlett Packard's San Jose facility:

   - Stripper Solvent
   - Isopropyl Alcohol
   - Trichloroethane (TCA)
   - n-Butyl Acetate
   - Acetone
   - Freons
   - Methanol
   - Xylenes

3. Further chemical engineering studies, specifications and design are recommended prior to installation of any solvent recycling equipment.

1.0 INTRODUCTION

Many microelectronics companies like Hewlett Packard in the State of California manufacture high-quality electronic components. Hewlett Packard's San Jose facility disposed of approximately 38,000 gallons of microchip manufacturing solvent waste in 1987. The purpose of this project was to evaluate the feasibility of recycling solvent wastes to reduce the volume of solvents requiring off-site disposal.

The manufacturing processes required to fabricate high-quality computer microchips at this facility are extremely complex and adhere to strict quality control measures. These processes generate organic solvent wastes which generally require offsite disposal. Microchip fabrication quality control measures restrict the use of any solvent that does not meet high purity standards. For these reasons, effective recycling of organic solvents within a fabrication process must not only adhere to strict purity standards but must include detailed chemical engineering knowledge of the fabrication process and cooperation from fabrication personnel.

Fabrication steps required to produce microchips generate a substantial volume of waste liquids containing organic solvents. Generally, these spent solvents must be transported to a licensed treatment facility where they are 1) dewatered, 2) separated into chlorinated and nonchlorinated solvent groups, and 3) purified for potential resale. Solvents which cannot be resold are normally incinerated. This practice is not only expensive with respect to solvent waste treatment and disposal but requires the purchase of large volumes of new solvent for replacement. This practice is considered undesirable environmentally and economically as a long term mechanism for waste disposal.

This project has reviewed various processes to reduce, recycle and/or treat solvent wastes in a manner such that disposal costs and disposal volume are significantly reduced. The methods evaluated at various wafer manufacturing stages included, but were not limited to solvent waste segregation, solvent

2.0 RESULTS AND DISCUSSION

2.1 DESCRIPTION OF THE MICROCHIP MANUFACTURING PROCESS

2.1.1 General Processes

The microchip manufacturing process involves the application of a series of standard procedures that are common to most electronics manufacturing industries. In general, these procedures are either currently being applied or could be applied to the Hewlett Packard facility in San Jose.

The microelectronics industry has significantly expanded in the last two decades. This has been associated with development of microelectronics technology, specifically semiconductor devices.

The development first of germanium, then silicon diodes, followed by the transistor and integrated circuit, was the major factor in the evolution of microelectronics.[9] An important property of semiconductor materials is that they are neither good insulators nor good conductors, but rather, semiconductors.

Equally important is that the electrical conductivity of semiconductors can be enhanced radically with small changes in chemical composition. Unlike other electrical devices which depend on the flow of electric charges through a vacuum or gas, semiconductor devices use the flow of current through a solid. They have no filaments or heaters and require very little power. This results in benefits relating to reliability, better performance and economy in semiconductor devices.

The production of silicon ingots and wafers from which microchips are produced involves a complex high temperature furnace growth process. Each wafer can yield several hundred individual chips.

Circuits are designed, reduced to final size and printed on glass plates called masks. Each wafer is coated with photoresist, which develops much

LEDs are fabricated from single-crystal GaAs in which p-n junctions are formed by the addition of suitable doping agents--typically silicon or chromium.

Microwave IC devices are a specialized form of integrated circuit which is used as a high-frequency amplifier. The major processing steps include liquid-phase epitaxial deposition, fabrication and non-fabrication processing similar to silicon device manufacturing.

Processing steps that are generally applied in manufacturing of silicon and GaAs microchips at the Hewlett Packard facility in San Jose are briefly described below. Identifying these steps will aid in the characterization of various solvent waste sources.

Ingot Growth

The process of ingot growing involves the introduction of the material in elemental forms, plus small quantities of dopant material--silicon, tellurium or chromium at elevated temperatures and controlled pressures. The reaction normally takes place in sealed quartz ampules.

Ingot and Remelt Sandblasting/Cleaning

The single-crystal GaAs ingots and polycrystalline defects must be sand-blasted and cleaned to remove exterior oxides and contaminants. The sandblasting is done in a glove-box type bead blaster utilizing either silicon carbide or calcined alumina blasting media. Wet cleaning is done in wet chemical baths provided with local exhaust ventilation and utilizing aqua regia, or alcohol rinses (isopropyl alcohol and/or methanol).

Ingot Cropping

The ends or tails of the single-crystal ingot are removed using a water lubricated single-banded diamond saw with various coolants added to the water.

Wafer Etching

Silicon wafers are placed in fluorinated plastic cassette holders and loaded into either manual chemical etch tanks or into an automated etching machine. The etching solutions could contain nitric acid, hydrofluoric acid or acetic acid.

The wafer etching process removes surface damage to the wafers, and reduces their thickness.

For GaAs, various mixtures of wet chemical acid solutions are used in plastic baths in locally exhausted etch stations, some of which are provided with laminar High Efficiency Particulate Air (HEPA) filtered supply systems vertically mounted. The primary acids in use generally are sulfuric (H_2SO_4), hydrofluoric (HF), hydrochloric (HCl) and phosphoric (H_3PO_4). As in silicon processing, hydrogen peroxide (H_2O_2) could be used with sulfuric acid, with ammonium hydroxide (NH_4OH) used as a caustic etch. A cyanide solution (sodium or potassium) can also be used for etching aluminum.

Polishing

Silicon wafers are initially mounted onto a metal carrier plate. The carrier is then attached by vacuum to the polishing machine. Generally a two-step process is performed--first, "stock removal", which provides an initial polish and decreases wafer thickness, and secondly, a "finish" polish to achieve a mirror-like exterior surface. The polishing solution contains sodium hydroxide (NaOH), colloidal silica and water and is automatically dispensed during polishing.

GaAs wafers are physically mounted to a mechanical polishing machine which uses a sodium bicarbonate, 5% chlorine, water and collodial silicon slurry for polishing.

Backlapping

Backlapping is done to remove deposited materials (GaAsP, Si_3N_4, etc.) from the backside of the wafer. The wafers are wax mounted to a lapper plate and wet lapped with a colloidal silica slurry. Then, the wax is removed by wet stripping the wafers in an organic stripper containing phenol, sulfonic acid and chlorobenzenes in a locally exhausted wet chemical etch station. Finally, the wafers are dipped in baths and vapor degreased with 1,1,1-trichloroethane.

2.1.2 Hewlett Packard Process

The Hewlett Packard (HP) facility in San Jose is located on Trimble Road about one tenth of a mile north of Highway 101. The general location of the facility is shown in Figure 2.1-1. The facility layout consists of the manufacturing areas, storage areas and parking areas. A plot plan of the HP facility is presented in Figure 2.1-2.

The microchip manufacturing process performed at the HP facility in San Jose generally involves all of the above-described steps. Three (3) fabrication areas inside the facility are used for the production of microchips. These fabrication areas include Microwave Semiconductor Division (MSD), Optical Communication Division (OCD), and Optoelectronics Division (OED). The first two fabrication areas (MSD and OCD) are located in building 90 with the third area (OED) located in building 91.

Microwave Semiconductor Division (MSD)

The MSD fabrication process area consists of bipolar and diode manufacturing areas where masking, etching, plating, wet bath, and metals application steps are performed. Figure 2.1-3 shows the floor plan of the MSD fabrication area. A "Clean Room" atmosphere is maintained throughout the processing area.

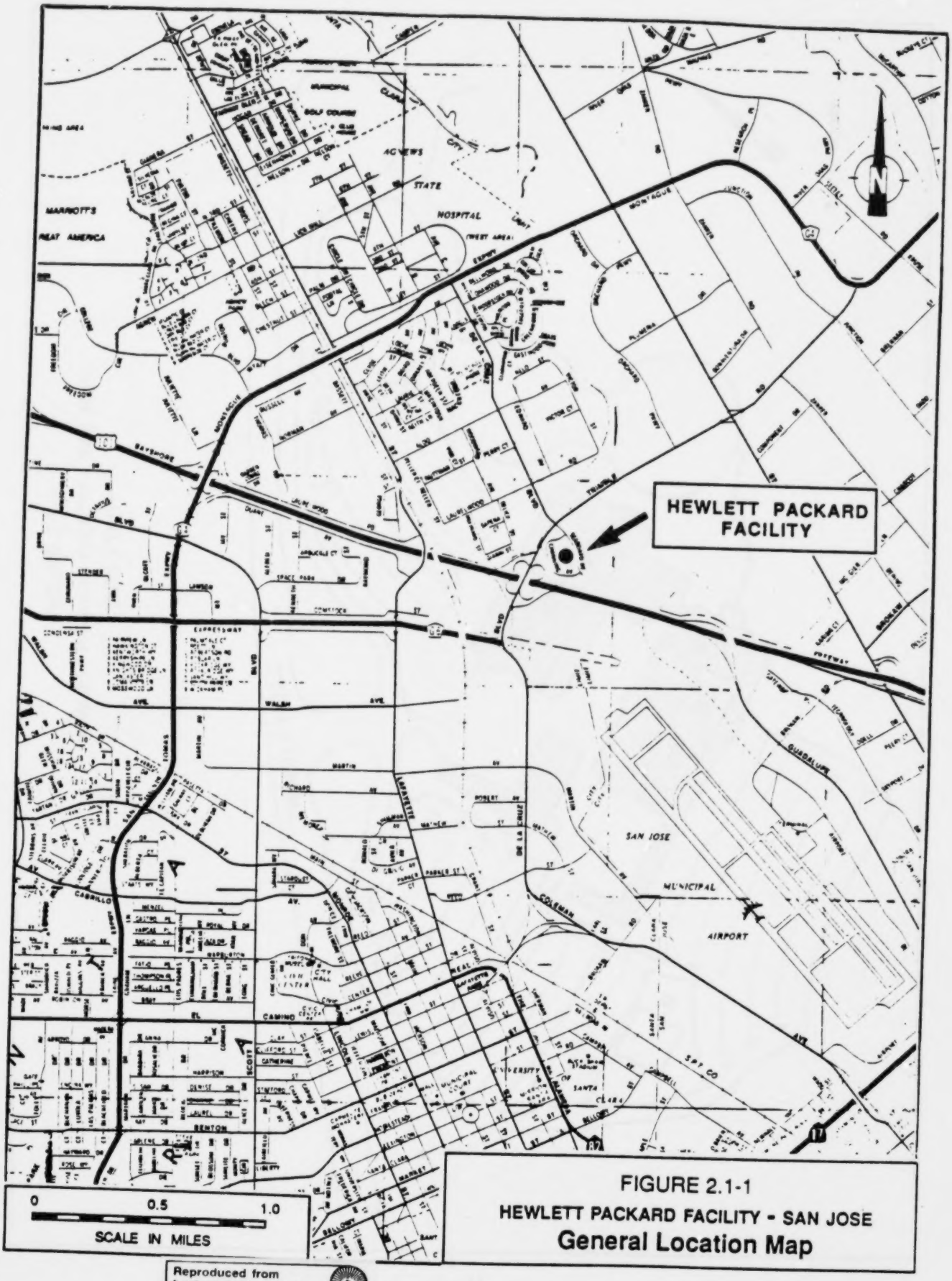


FIGURE 2.1-1
HEWLETT PACKARD FACILITY - SAN JOSE
General Location Map

Reproduced from best available copy.

FIGURE 2.1-2

HEWLETT PACKARD FACILITY - SAN JOSE

Site Plan

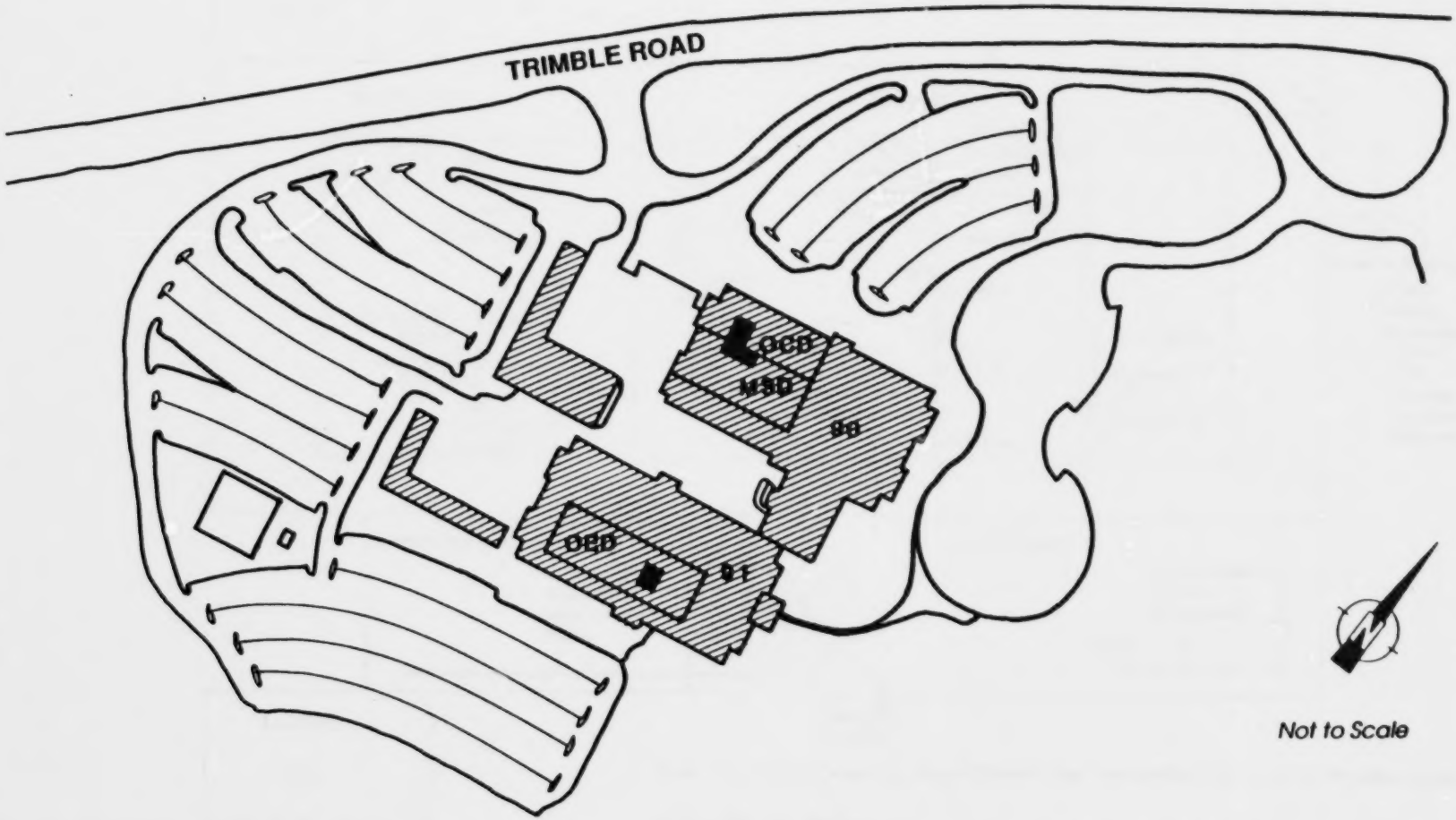
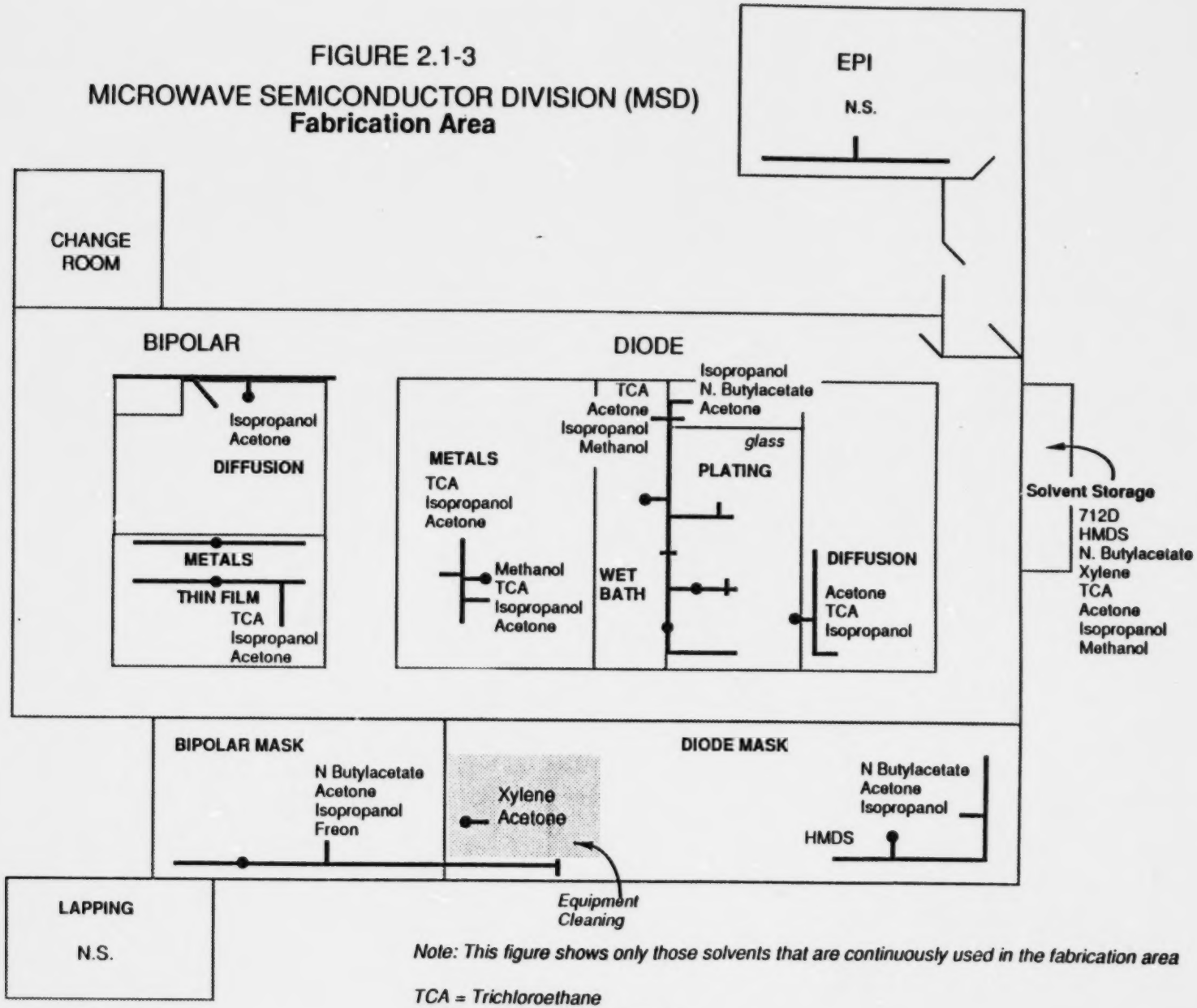


FIGURE 2.1-3

MICROWAVE SEMICONDUCTOR DIVISION (MSD)
Fabrication Area



Note: This figure shows only those solvents that are continuously used in the fabrication area

TCA = Trichloroethane
HMDS = Hexamethyl Disilozane
712D = Chemical Stripper Mixture

— Solvent Drain System 1
N.S. No Solvents Used

Organic solvents are primarily used in etching, masking, plating and cleaning processes. Organic solvents are also used for cleaning positive and negative photoresists, and removing wax from wafers. The amounts of organic solvents used in other areas are insignificant. Other uses of organic solvents are for cleaning equipment and removing labels. There are two separate piping/drainage systems for the waste solvents. Figure 2.1-4 illustrates the process steps where major solvent usage occurs.

Optical Communication Division (OCD)

This fabrication area is also located in building 90. Activities associated with OCD fabrication area also require a "Clean Room" atmosphere. Special clothing and an "air shower" are provided to keep dust and particles from entering the fabrication area. Process areas include gold room, sputter area, pin diode area, masking, and etching. Figure 2.1-5 shows the floor plan for OCD fabrication area. The primary use of organic solvents are for cleaning wafers. Equipment cleaning also requires some small amount of solvent use. There are two separate piping/drainage systems for the waste solvents. Figure 2.1-6 indicates the major solvent usage areas.

Optoelectronics Division (OED) Fabrication Area

The OED fabrication area is located in building 91 and is separate from the other two fabrication areas. Process fabrication areas consist of aluminum and gold evaporation, masking, silox clean, hot wall nitride, diffusion, backlap cleaning and equipment maintenance. The floor plan for OED fabrication area is shown in Figure 2.1-7. Solvents are primarily used during lapping and polishing the wafers to dissolve wax. This wax holds wafers in place during lapping and polishing. Some solvents are used in vapor degreasing of parts and equipment. Again, a "Clean Room" atmosphere is maintained throughout the processing area. Two separate piping/drainage systems for waste solvents also exist in this fabrication area. Figure 2.1-8 shows the process areas using organic solvents.

FIGURE 2.1-4
MICROWAVE SEMICONDUCTOR DIVISION (MSD)
FABRICATION
Solvent Use Areas

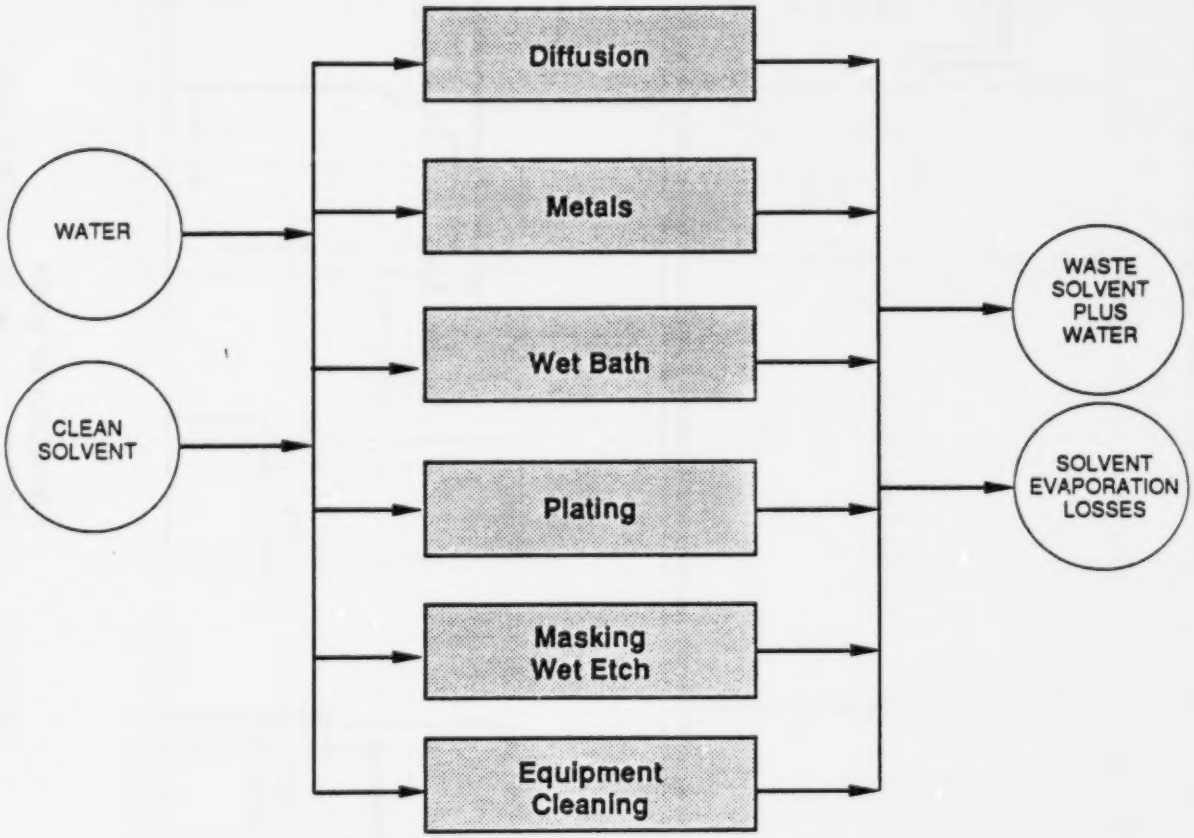
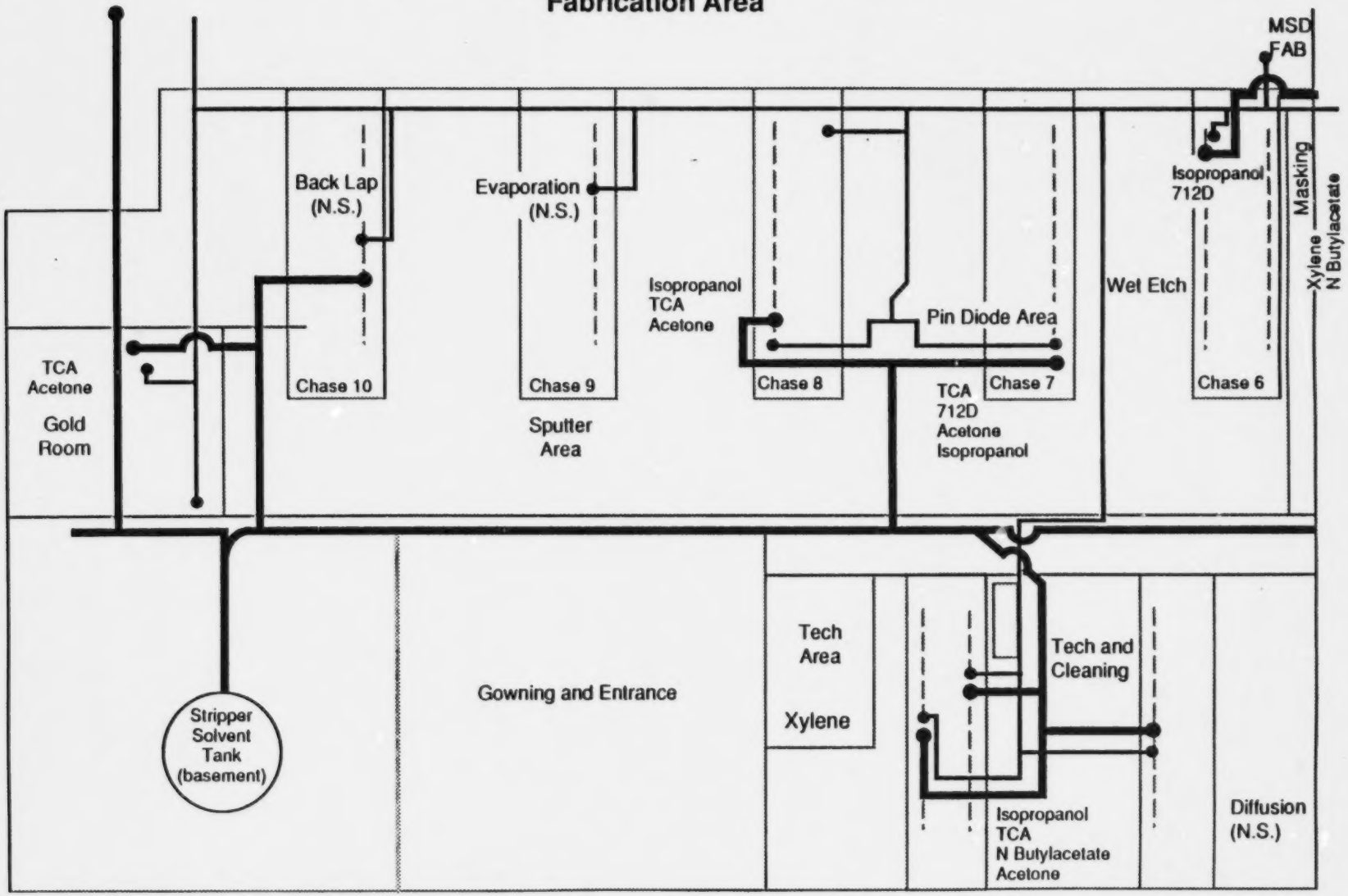


FIGURE 2.1-5

OPTICAL COMMUNICATION DIVISION (OCD)

Fabrication Area



N.S. No Solvents Used

Solvent Drain System 1

Solvent Drain System 2

Note: This figure shows only those solvents that are continuously used in the fabrication area.

FIGURE 2.1-6
Optical Communication Division (OCD)
Fabrication
Solvent Use Areas

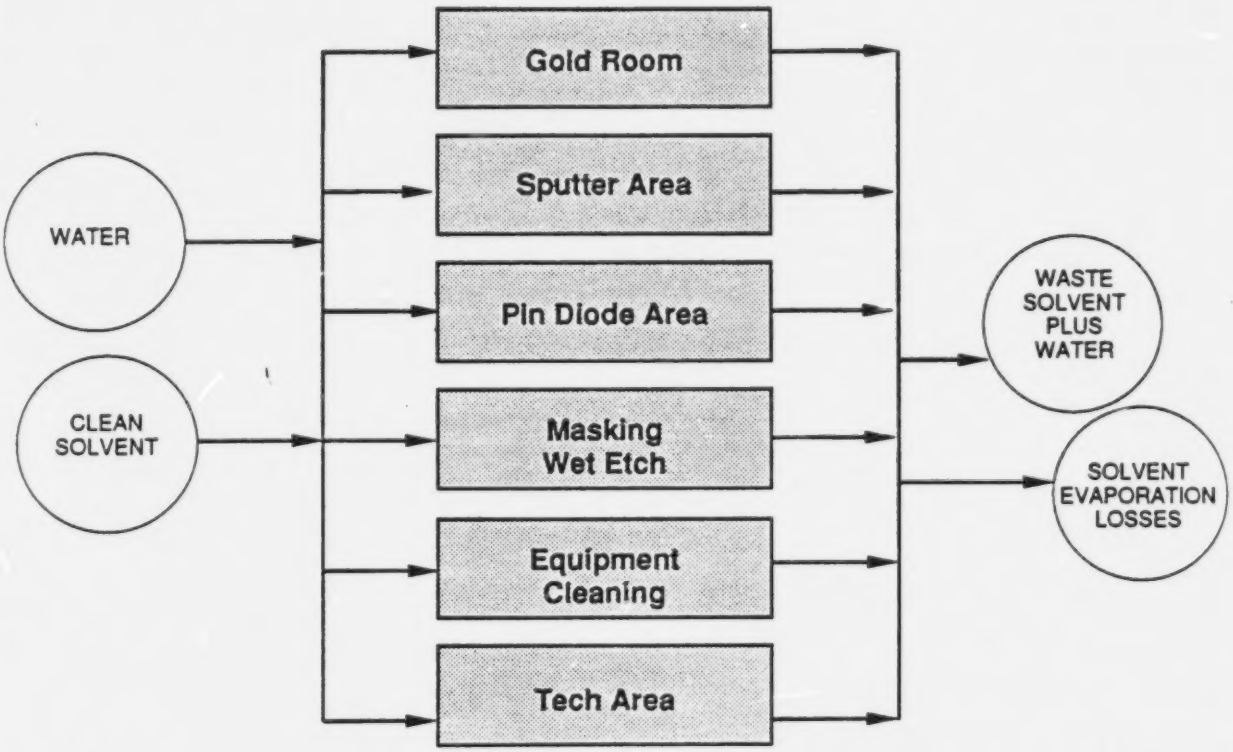
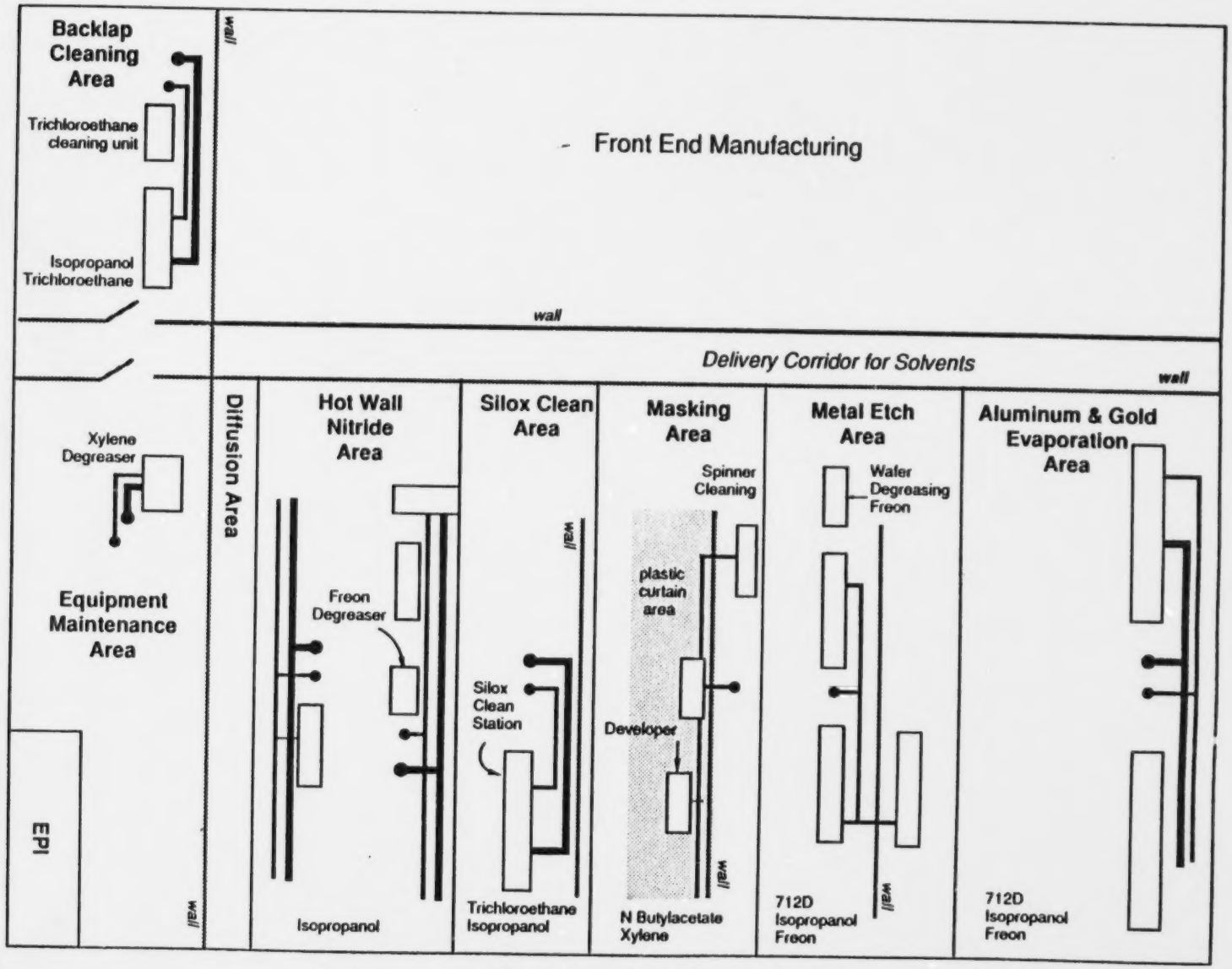


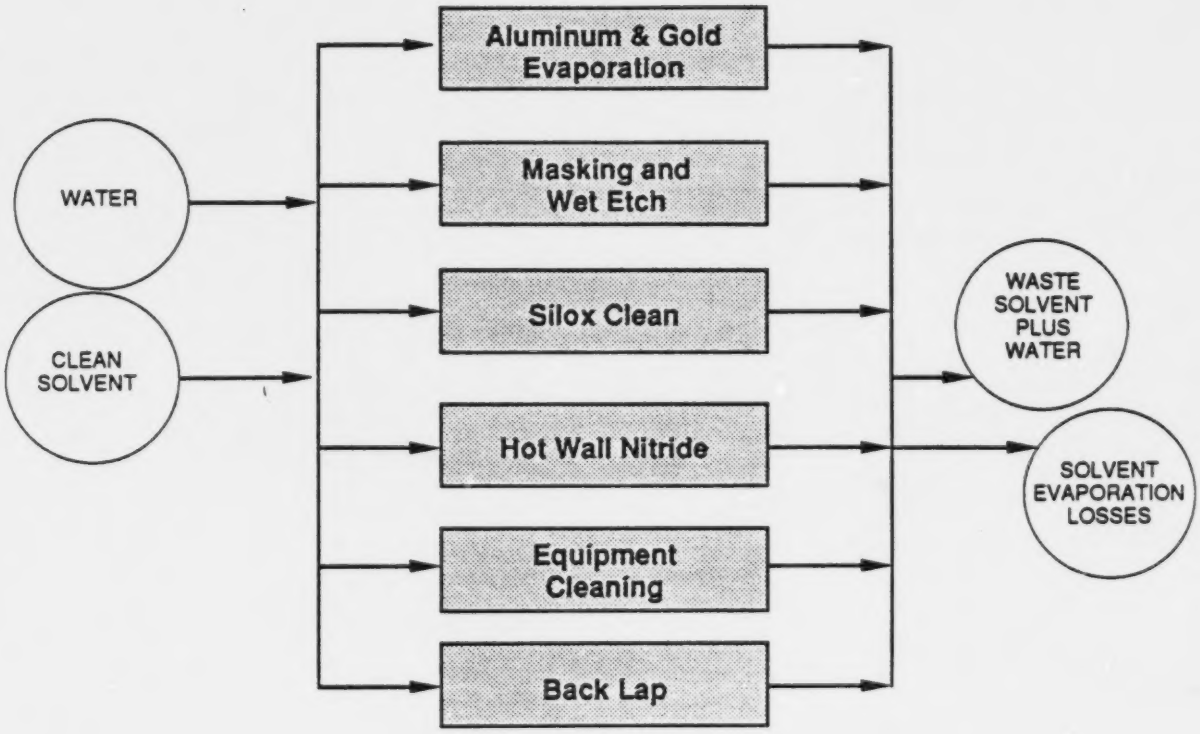
FIGURE 2.1-7
OPTOELECTRONICS DIVISION (OED)
Fabrication Area



Solvent Drain System 1
Solvent Drain System 2

Note: This figure shows only those solvents that are continuously used in the fabrication area.

FIGURE 2.1-8
Optoelectronics Division (OED)
Fabrication
Solvent Use Areas



2.2 CHEMICAL CHARACTERIZATION OF WASTE SOLVENT STREAMS

In order to accomplish the solvent waste reduction study at the Hewlett Packard facility, a detailed evaluation of the manufacturing processes was required. The evaluation of the processes allowed identification of all steps and areas where organic solvents were utilized.

Waste solvents are generated in the process areas of the three manufacturing areas (MSD, OCD and OED) where solvents are used. A portion of solvent volume is lost through evaporation during the manufacturing processes. Some water is used in the processes and is discharged from the areas along with the waste solvents. All generated waste solvents and small amounts of water exit through a common drainage system to be collected into two holding tanks. One of the holding tanks is located near Building 90 and the other one is near Building 91. Currently, the collected waste solvents are periodically pumped out of the tanks and shipped to an off-site recycler. Two of the three manufacturing areas are equipped with two separate drainage systems to allow separation of solvent types.

During 1987 about 38,000 gallons of solvent waste were generated and collected from the HP facility. It should be noted that this organic solvent waste includes some water. The quantity of organic solvents that were lost due to evaporation were not included in the 38,000 gallon volume but are thought to be approximately equal to the included water based on HP's air monitoring data. The volume of recyclable solvent waste is considered the largest fraction of this figure. This annual volume represents solvent waste generated from all areas in the facility which include non-fabrication areas that may not be amenable to recycling on-site.

Measurement of the amounts of solvent waste generated in each process step were obtained from extensive discussions with employees involved in these steps. Each step requires an exact amount of solvent of a particular type. With numerous complex process steps in each area, the amounts of each solvent could be determined with reasonable accuracy as well as the locations within the process areas where these solvents were used. The ultra-high purity

TABLE 2.2-1

SUMMARY OF ANNUAL SOLVENT USAGE
(GAL)
HEWLETT PACKARD SAN JOSE FACILITY

Solvent Type	MSD	OCD	OED	Total
Acetone	1,406	781	1,360	3,547
Isopropyl Alcohol	1,302	3,691	4,744	9,737
Methanol	298	487	652	1,437
Trichloroethane (TCA)	1,117	702	3,864	5,683
N-Butyl Acetate	178	472	443	1,092
Freons and Genesolve	220	110	280	610
Xylenes and Mask Cleaners	794	392	126	1,313
Stripper Solvents	1,852	4,877	2,814	9,542
Developers	--	496	472	986
Photoresists	103	--	100	203
Hexamethyldisilizane (HMDS)	150	--	--	150
Toner	--	--	300	300
TOTAL	7,420	12,008	15,152	34,580

TABLE 2.2-2

Annual Solvent Usage
MSD Fabrication Processes
(Gal)

Solvent Type	Diffusion	Metals	Wet Bath	Plating	Masking & Wet Etch	Equipment Cleaning	Total
Acetone	190	76	8	116	796	221	1,406
Isopropyl Alcohol	264	104	148	176	522	88	1,302
Methanol	4	-	4	-	-	290	298
Trichloroethane (TCA)	86	104	28	200	546	152	1,117
N-Butyl Acetate	24	-	-	-	52	102	178
Freons and Genesolve	40	-	60	-	30	90	220
Xylenes and Mask Cleaners	36	-	-	12	746	-	794
Stripper Solvents	138	95	80	326	1,163	49	1,852
Developers	-	-	-	-	-	-	-
Photoresist	12	-	-	-	91	-	103
Hexamethyldisilazane (HMDS)	-	-	-	-	150	-	150
Toner	-	-	-	-	-	-	-
TOTAL	794	379	328	830	4,076	992	7,420

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TABLE 2.2-3

Annual Solvent Usage
OCD Fabrication Processes
(Gal)

Solvent Type	Gold Room	Sputter Area	Pin Diode Area	Masking Wet Etch	Equipment Cleaning	Tech Area	Total
Acetone	115	132	140	271	123	-	781
Isopropyl Alcohol	248	384	680	2,203	74	102	3,691
Methanol	48	67	131	-	-	241	487
Trichloroethane (TCA)	124	100	118	249	111	-	702
N-Butyl Acetate	-	-	-	97	375	-	472
Freons and Genesolve	-	-	110	-	-	-	110
Xylenes and Mask Cleaners	-	-	-	208	-	184	392
Stripper Solvents	-	1,020	925	2,740	192	-	4,877
Developers	-	-	245	251	-	-	496
Photoresist	-	-	-	-	-	-	-
Hexamethyldisilazane (HMDS)	-	-	-	-	-	-	-
Toner	-	-	-	-	-	-	-
TOTAL	535	1,852	2,349	5,770	975	527	12,008

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TABLE 2.2-4

Annual Solvent Usage
OED Fabrication Processes
(Gal)

Solvent Type	Aluminum and Gold Evaporation	Masking and Wet Etch	Silox Clean	Hot Wall Nitride	Equipment Cleaning	Back Lap	Total
Acetone	194	426	341	214	185	-	1,360
Isopropyl Alcohol	372	2,844	522	379	382	245	4,744
Methanol	212	-	320	120	-	-	652
Trichloroethane (TCA)	375	2,213	508	188	380	200	3,864
N-Butyl Acetate	-	117	45	-	281	-	443
Freons and Genesolve	119	89	-	72	-	-	280
Xylenes and Mask Cleaners	-	26	-	-	100	-	126
Stripper Solvents	121	2,050	-	200	443	-	2,814
Developers	-	284	-	188	-	-	472
Photoresist	-	100	-	-	-	-	100
Hexamethyldisilazane (HMDS)	-	-	-	-	-	-	-
Toner	-	300	-	-	-	-	300
TOTAL	1,393	8,449	1,736	1,361	1,771	445	15,152

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FIGURE 2.2-1
MICROWAVE SEMICONDUCTOR DIVISION (MSD)
FABRICATION
Annual Solvent Usage

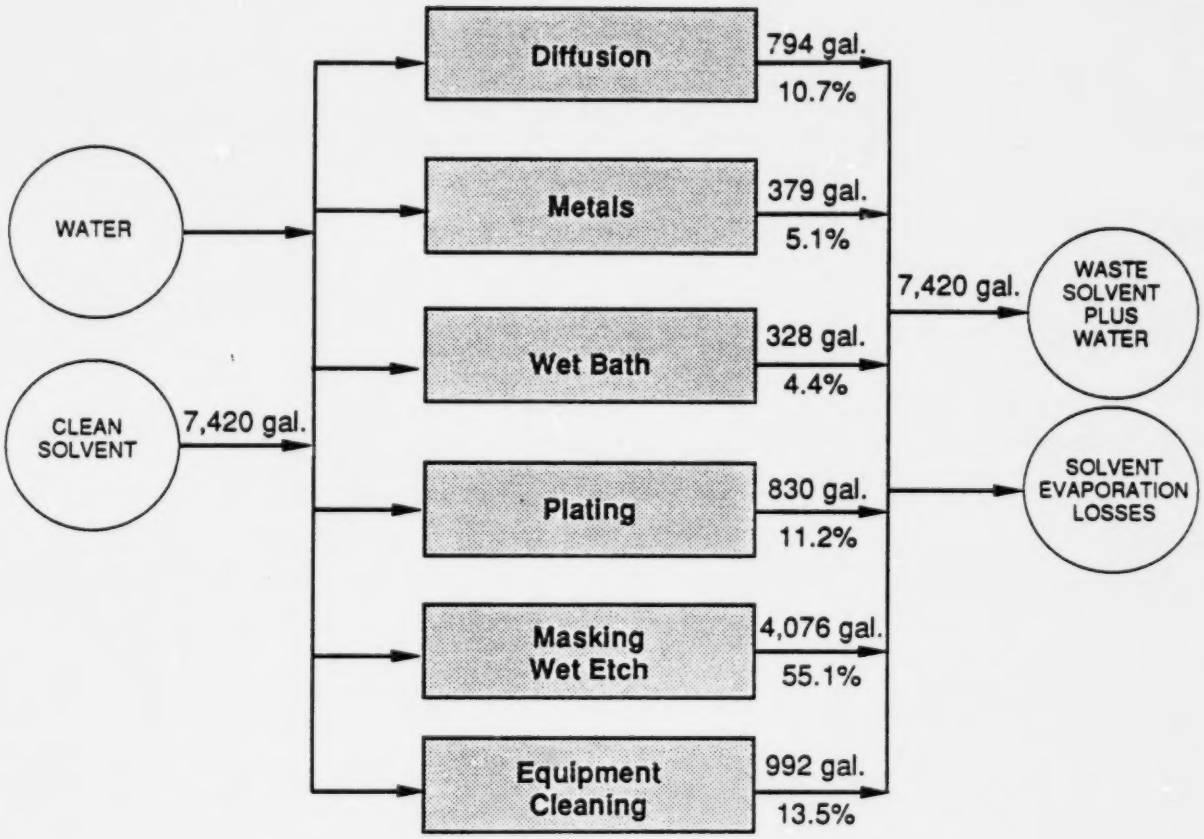

FIGURE 2.2-2
Optical Communication Division (OCD)
Fabrication
Annual Solvent Usage

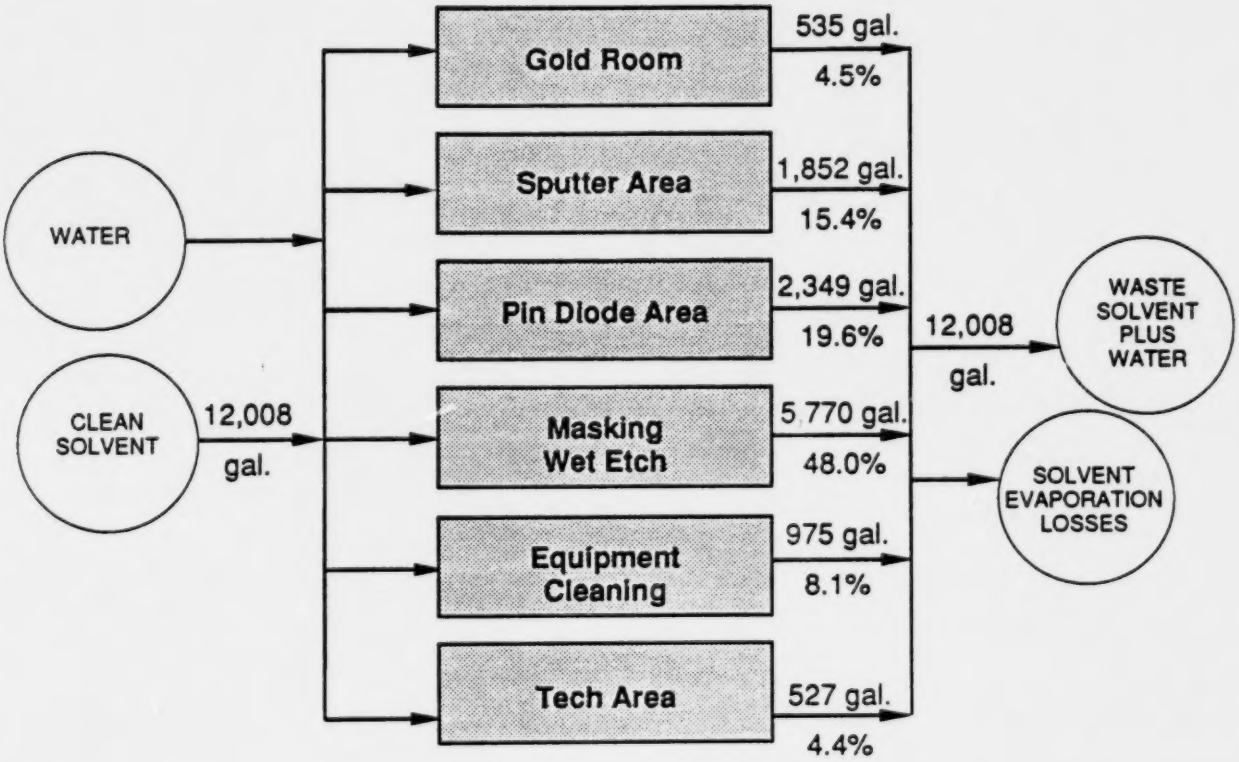

FIGURE 2.2-3
Optoelectronics Division (OED)
Fabrication
Annual Solvent Usage

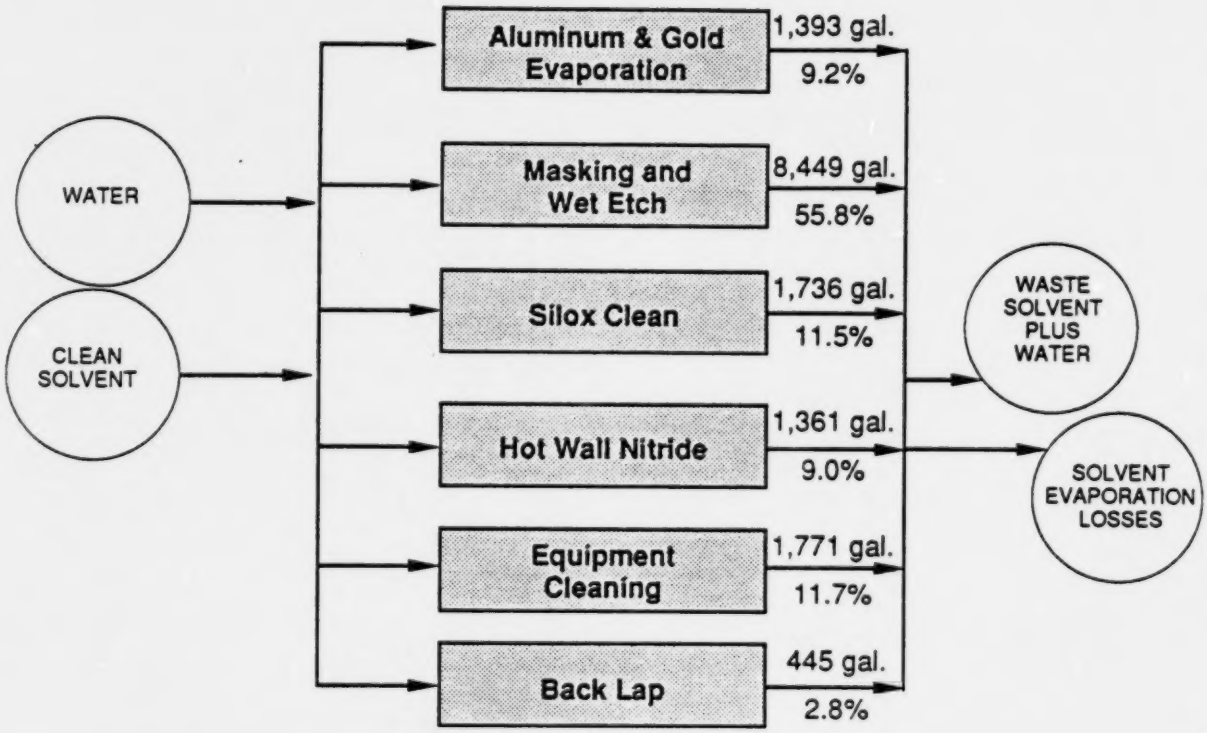

TABLE 2.2-5

Solvent Waste Stream Characteristics
(3 separate streams sampled)

Parameter	Solvent	Solvent with Stripper	Stripper	HP Site Average
Flash Point (°F)	-	-	-	53
Boiling Point (°F)	156	184	210	183
Density (g/L)	958	1,028	1,122	1,036
Viscosity at 77°F (CS)	1.18	5.61	6.74	4.51
Solubility in H_2O (ml/10 ml)	<1	Suspension	Suspension	Suspension
Percent Water (%)	1.9	34.1	9.2	15.0
Heating Value (Btu/lb)	12,719	9,805	11,751	11,425
Heavy Metals (mg/kg)				
Antimony	<0.05	<0.05	<0.5	<0.5
Arsenic	0.14	0.96	0.13	0.41
Barium	<0.5	<0.5	<0.5	<0.5
Beryllium	<0.3	<0.3	<0.3	<0.3
Cadmium	<0.2	<0.2	<0.2	<0.2
Chromium	<0.5	0.76	1.2	0.65
Cobalt	<0.5	<0.5	<0.5	<0.5
Copper	10.8	4.7	<0.5	5.17
Lead	2.7	5.8	<0.8	2.8
Mercury	<0.1	<0.1	<0.1	<0.1
Molybdenum	<0.5	<0.5	<0.5	<0.5
Nickel	0.29	0.71	<0.2	0.33
Selenium	<0.2	<0.2	<0.2	<0.2
Silver	<0.5	<0.5	<0.5	<0.5
Thallium	<2	<2	<2	<2
Vanadium	<0.5	<0.5	<0.5	<0.5
Zinc	7.3	13.3	3.3	7.97
Organic Components (mg/kg)				
Methanol	39,072	11,508	1,727	17,436
Isopropyl Alcohol	119,101	107,893	68,700	98,565
Acetone	39,393	51,258	92	30,248
Toluene	465	40	<5	168
Xylene	168,936	2,847	2,698	58,160
N-Butylacetate	187,429	4,933	<5	64,121
Trichlorobenzene	12,138	47,328	697,560	252,342
Phenol	-	-	-	8,667
Trichloroethane	-	-	-	120,500
Tetrachloroethane	-	-	-	2,600
Freon	-	-	-	400
Dichloroethane	-	-	-	177

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2.3 CHARACTERIZATION OF SOLVENT PROPERTIES

The organic solvents used in Hewlett Packard's San Jose facility fall into three general categories (1) flammable solvents (2) chlorinated solvents, and (3) stripper solvents. Tables 2.3-1 and 2.3-2 show the physical properties for the more common (large volumes) solvents used. Tables 2.3-3 and 2.3-4 delineate health and safety characteristics concerning the above materials. Table 2.3-5 presents data regarding possible azeotropic mixtures of organic solvents.

These data were evaluated so that solvent substitution or comingling could be considered to reduce solvent waste and to reduce disposal or recycling costs. Below is a brief discussion for the solvents used in highest volume at Hewlett Packard's San Jose facility.

2.3.1 Flammable Solvents

Acetone

This is a highly volatile non-chlorinated solvent. It is miscible with water, alcohol and most oils. It forms azeotropic boiling mixtures with methanol. This should not be of significance in any distillation because of the differences in boiling points of the two materials and the relative proportion of the materials should not approach the azeotropic level (see Table 2.3-5). Due to its inherent flammability, care must be taken to avoid exposure to open flame and sparks. The Threshold Limit Valve (TLV) for acetone of 1,000 ppm (in air) is that concentration to which nearly all workers can be exposed day after day without adverse effect[2]. It is recommended that all personnel handling this material wear suitable gloves and safety glasses.

N-Butyl Acetate

N-butyl acetate is slightly soluble in water and may form an azeotropic mixture with water (Table 2.3-5). However, it does not appear that this

TABLE 2.3-1

PHYSICAL PROPERTIES OF ORGANIC SOLVENTS

SOLVENT	MOLECULAR[1] WEIGHT g	NORMAL[1,3] BOILING POINT °F	FLASH[3,5] POINT °F	VAPOR[1,5] PRESSURE PSIA	VISCOSITY[1] @) 77°F lb/ft-sec x 10-4	SURFACE[1,6] TENSION @ 68°F lb(f)/ft x 10-3	WATER[4,5,6] SOLUBILITY PPM at 77°F	HEAT OF[1] VAPORIZATION Btu/lb	HEAT OF[1] COMBUSTION Btu/lb	SPECIFIC[1,5] GRAVITY @68°F
Acetone	58.08	133.2	15.1	3.87@72.9°F	2.12	1.54	Infinite	230.4	14,676	0.79
n-Butyl Acetate	116.2	259	98	0.17@68°F	4.96	—	8333	170.1	—	0.88
Freon TMS	—	—	None	5.28	—	—	Negligible	—	—	1.52
Trichloro Trifluoroethane (Freon)	187.4	117.9	None	7.7@87°F	4.57	1.30	350	63.2	—	1.57
Genesolv D (Freon)	187.4	117.9	None	5.6@70°F	—	—	350	—	—	1.57
Isopropyl Alcohol	60	181	53	0.64@68°F	14.1	1.49	Infinite	228	14,262	0.792
Hexamethyldisilazane (HMDS)	161	255	77	0.39@68°F	—	—	Insoluble	—	—	—
Methyl Alcohol	32	148	54	1.8@86°F	3.99	1.55	Infinite	473	9,278	0.792
1-1-1 Trichloroethane (TCA)	156	167	None	1.9@68°F	8.1	1.77	700	176	—	1.325
Xylenes	106	278-296	81-115	0.19@68°F	4.7	2.0	146-170	287	18,516	0.869

(1) Handbook of Chemistry and Physics - 68th ED
(2) Chemical Engineer's Handbook - Perry - 5th ED.
(3) Condensed Chemical Dictionary - Hawley - 10th ED.
(4) Merck Index
(5) Hewlett Packard Safety/Chemical Drawing
(6) Guide to Solvent Waste Reduction Alternative - ICF Consultants
\- No Data Available (Proprietary Mixture)

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TABLE 2.3-2
PHYSICAL PROPERTIES OF PROPRIETARY SOLVENT FORMULATIONS

Solvent	Normal Boiling Point °F	Flash Point °F	Vapor Pressure PSIA	Water Solubility PPM@ 770°F	Specific Gravity @68°F	Remarks
Developer	—	80	0.38@68°F	—	0.872	99% Xylene
Waycoat Photo Resist	—	81	0.2@68°F	—	0.9	85% Xylene
Micro Resist Developer	—	110	<0.1@68°F	Negligible	0.79	95-100% Stoddard Solvent
Photo Resist Developer	279	73-100	0.19	—	<1.0	10-30% Aromatic Hydrocarbon >60% Aliphatic Hydrocarbon
Photo Resist Developer	311-410	108	<0.2@68°F	Negligible	0.79	Mixture of Petroleum Solvents
Photo Resist (Negative)	255°	98	—	—	1.08	48% 2-Ethoxyethylacetate, 5% NBA, 5% Xylene
Photo Resist (Positive)	260°	104	—	—	~1.05	52% 2-Ethoxyethylacetate, 6% NBA, 6% Xylene
Utrasonic Degreaser	—	—	0.06	Negligible	1.88	Perfluoroisobutylene
Test Media	—	—	5.0	Negligible	1.70	Perfluoro Alkane
Stripper 712D	—	185		Complete Emulsion	1.163	Dodecyl Benzene Sulfonic Acid, 1-2-4 Trichloro Benzene, Phenol - PH = 2.4-2.6 (1% Solution)
Remover	—	>190		Complete	~0.96	75% Glycol Ether, PH = 12
Resist Stripper-J100	—	>400	0.46@68°F	Emulsifies	1.27	63% Methylene Chloride & Chlorobenzenes 23% Sulfonic Acids - 14% Phenols and Derivatives
Microstrip	—	169	0.97@68°F	Insoluble	—	75% Chlorinated Solvents - Orthocresol Dodecylbenzo Sulfonic Acid, Perchloroethylene O - Dichlorobenzene

NOTE: Physical Property Data Provided by Hewlett Packard Safety/Chemical Drawings
- No Data Available

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TABLE 2.3-3

HEALTH AND SAFETY DATA FOR ORGANIC SOLVENTS

Material	Flammability		Extinguishing Media	Toxicity		Compatibility
	Flash Point °F	Explosive Limits %		TLV/TWA ppm	STEL ppm	
Acetone	0	2.6(l.e.l)* 12.8 (u.e.l)*	CO_2, Dry Chemical	750	1,000	Incompatible with acids, oxidizers and chloroform avoid sparks and open flame
n-Butyl Acetate	72	1.4(l.e.l) 7.6(u.e.l)	CO_2, Dry Chemical	150	200	Incompatible with inorganic acids and oxidizing materials. Avoid sparks, open flame
Freon TMS See Trichlorotrifluorethane	—	—	—	—	—	
Trichloro Tri-fluoroethane	—	Non-Flammable	—	1,000	1,250	Incompatible with alkalies or alkaline Earth metals can be thermally decomposed to HF and HCL and possibly phosgene and chlorine
Genesol D See Trichlorotrifluorethane	—	—	—	—	—	
Isopropyl Alcohol	53	2.3(l.e.l) 12.7(l.e.l)	CO_2, Dry Chemical	400	500 (skin)	Incompatible with strong oxidizers, halogenated acids. Avoid sparks, open flame
Hexamethyldisilazane (HMDS)	77		CO_2, Dry Chemical	—	—	Incompatible with acids thermal decomposition releases ammonia fumes
Methyl Alcohol	54	7.3(l.e.) 36.0(u.e.l)	CO_2, Dry Chemical	200	300 (skin)	Incompatible with inorganic acids and oxidizers. Avoid sparks, open flame
1-1-1 Trichloroethane (TCA)	—	Non-Flammable	—	350	450	Thermal decomposition produces hydrogen chloride and small amounts of phosgene and chlorine. Slow hydrosis with water produces corrosive acid
Xylenes	81	1.0(l.e.l) 7.0 (u.e.l.)	CO_2, Dry Chemical	100	150	Incompatible with strong oxidants - avoid sparks, open flame

* l.e.l. - lower explosive limit
u.e.l. - upper explosive limit

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TABLE 2.3-4

HEALTH AND SAFETY DATA FOR PROPRIETARY SOLVENT FORMULATIONS

Material	Flammability: Flash Point °F	Flammability: Explosive Limits % (1)	Extinguishing Media (1)	Toxicity: TLV/TWA ppm (1), (2)	Toxicity: STEL ppm	Compatibility
Developer	See Xylenes					
Waycoat Photo Resist	See Xylenes					
Micro Resist Developer	110	0.8 (l.e.l) 5 (u.e.l)	CO_2 Dry Chemical	200	1,050	Incompatible with strong oxidizers Avoid heat, sparks, open flame.
Photo Resist Developer	73-100	1.0(l.e.l)	Regular Foam, CO_2, Dry Chemical terminates etc.)	5 (skin) - lowest value of compoenents		Avoid contact with strong oxidizing agents (e.g. nitric acid, permanganates, etc.).
Photo Resist Developer		0.9 (l.e.l) 6.0 (u.e.l)	Foam, Dry Chemical	100	—	Incompatible with strong oxidants.
Photo Resist (Negative)	98	—	CO_2 H_2O, Alcohol	5 (skin)	—	Emits highly toxic fumes under fire conditions.
Photo Resist (Positive)	104	—	CO_2 H_2O, Alcohol	5 (skin)	—	Emits highly toxic fumes under fire conditions.
Ultrasonic Degreaser	Non-Flammable		N.A.	None established		Incompatible with molten alkali metals. Thermal decomposition will emit fluoride fumes.
Test Media	See Ultrasonic Degreaser					
Stripper 712D	158	1.0(l.e.l) 6.0(u.e.l)	CO_2 Dry Chemical	5	—	Incompatible with highly alkaline materials and strong oxidizing agen
Remover	>190	—	Water; CO_2, Dry Chemical	50	—	Incompatible with strong oxidants.
Resist Stripper-J100	>400	—	CO_2	~100	—	Incompatible with oxidizing agents.
Micro Strip	169	2.0(l.e.l) 9.0(u.e.l)	CO_2, Foam, Dry Chemical	~30	—	Incompatible with strong oxidants. High heat may reach decomposition temperatures, emitting highly toxic fumes of chlorides, sulfuric acid, etc.

(1) Hewlett Packard Safety/Chemical/Drawings
(2) TLVS - Threshold Limit Values For Chemical Substances - American Conference of Governmental Industrial Hygienists

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TABLE 2.3-5

AZEOTROPIC MIXTURES OF SOLVENTS

Solvent	Azeotropic Component	Weight % of Azeotropic Component	Boiling of Temperature of Mixture °F
Water	Isopropyl Alcohol	87.8	176.7
Water	n-Butyl Acetate	72.9	195.3
Water	m-Xylene	60	202.1
Water	1,1,2-Trichlorotri-fluoroethane	99	112.1
Methanol	Acetone	88	132.3
	1,1,2-Trichlorotri-fluoroethane	99	112.1
	Toluene	27.6	146.7
Isopropyl Alcohol	o-Xylene		Zeotropic
	Toluene	42	117.1
	Methyl Ethyl Ketone (MEK)	70	161.1
n-Butyl Acetate	Butyl Ether	5	258.6

Ref: Perry - Chemical Engineer's Handbook - 5th Edition
Handbook of Chemistry and Physics - 68th Edition

should be of concern, since the proportion of water would be well below that required for azeotropic boiling (73%). It should be stored away from acids, oxidizers sparks and open flames. The TLV for this chemical is 150 ppm in air. Since it is a skin irritant, personnel should wear gloves and safety glasses. Local exhaust of vapors is also recommended by the manufacturer.

Isopropyl Alcohol

Isopropyl alcohol (IPA) is the highest volume solvent used at the Hewlett Packard facility. It is soluble in water, other alcohols and acetone and is not azeotropic with any of the other solvents used. Besides its flammability, it is toxic by ingestion with a lethal dose of 100 cc.[12] The dermal TLV is 400 ppm[5]. According to the manufacturer's recommendation, safety glasses and protective gloves are necessary for worker protection.

Methyl Alcohol

This compound is highly flammable and toxic. It is completely soluble in water, other alcohols and is a solvent for many organic compounds. It is toxic by ingestion and can cause blindness.[12] The manufacturer/distributor recommends that this material be kept away from heat, sparks and open flame. Proper ventilation, gloves, and safety glasses are recommended for using this chemical. As previously mentioned, methanol forms an azeotropic mixture with acetone. It also forms an azeotropic boiling mixture with trichlorotrifluoroethane (Freon). However, the required proportion of the azeotropic component is so great that the probability of formation of an azeotropic boiling mixture is minimal.

Xylenes

Xylenes consist of 3 isomers; ortho, meta, para. These are insoluble in water and soluble in alcohols. They are toxic by ingestion and inhalation. The TLV in air is 100 ppm. m-Xylene and water can form an azeotropic mixture. However, the relatively high proportion of water required makes the probability of this occurring very low. According to the manufacturer's

recommendations, proper local exhaust, safety glasses and rubber gloves should be provided for workers handling this material.

2.3.2 Chlorinated Organic Solvents

1,1,1-Trichloroethane (TCA)

Trichloroethane has a low solubility in water. It is soluble in alcohols and is non-flammable but it is irritating to eyes and tissue. The TLV is 350 ppm in air. According to the manufacturer/distributor, local exhaust, safety glasses and protective gloves are required for workers handling the material.

Trichlorotrifluoroethane (Freon)

This compound is non-flammable and is toxic by inhalation and ingestion. It is also irrating to skin and eyes. The TLV is 1,000 ppm in air. It forms azeotropic mixtures with water and methanol. However, because freon is currently handled separately at Hewlett Packard due to its high cost, azeotropic problems are not expected. The manufacturer recommends that proper local exhaust be provided as necessary, safety goggles be worn, protective clothing and impervious gloves be worn if there is repeated or prolonged contact with the liquid. Freon-TMS and Genesolv-D are solvents used at Hewlett Packard and contain mainly trichlorotrifluoroethane.

2.3.3 Stripping Solvents

Stripper 712D

This consists of dodecylbenzene sulfonic acid, 1,2,4-trichlorobenzenes, hydrocarbons (C9-C12 paraffins, cycloparaffins, aromatics) and phenol. The stripper consists of less than 75% 1,2,4-trichlorobenzene and phenol. The dermal TLV for these compounds is 5 ppm.[5] Skin irritation and corrosive burns are possible with prolonged or repeated contact. According to the distributor, use of this material is recommended only with local hooded exhaust. This is a combustible liquid and should not be handled near heat,

2.4 IDENTIFICATION OF POTENTIAL WASTE REDUCTION PROCESSES

2.4.1 Source Reduction

Solvent waste reduction processes involve numerous chemical and physical treatment and separation techniques. Each process must be considered in light of the economic value of such recyling or treatment and how it will impact the overall production of the facility's end products. Figure 2.4.1 illustrates the general components that make up the consideration criterion for solvent waste reduction.

2.4.1.1 Solvent Waste Segregation

In general, segregation of chlorinated solvents from non-chlorinated solvents is recommended to facilitate waste reduction by increasing recyclability. Solvent waste piping layouts for each fabrication area at Hewlett Packard's San Jose facility are illustrated on Figures 2.4-2, 2.4-3, and 2.4-4. Separate chlorinated and non-chlorinated solvent drain systems are shown.

Representatives of commercial recycling facilities interviewed in a 1986 telephone survey were asked for recommendations on ways that generators can improve the recyclability of solvent wastes[1]. Segregation of solvent wastes was the most frequent suggestion with specific recommendations to: 1) minimize water mixing; 2) separate chlorinated from nonchlorinated solvent wastes; 3) separate aliphatic from aromatic solvent wastes; and 4) separate freons from methylene chloride.

Segregation of the process waste streams should significantly increase the recyclability and treatability of spent solvents. This improved operating practice can easily be implemented by increasing employee awareness of solvent disposal practices within each fabrication area. Each non-chlorinated and chlorinated solvent drain system would be used to accomplish this segregation by designating each to receive the proper type of spent solvent.

Figure 2.4-1

WASTE REDUCTION COMPONENTS

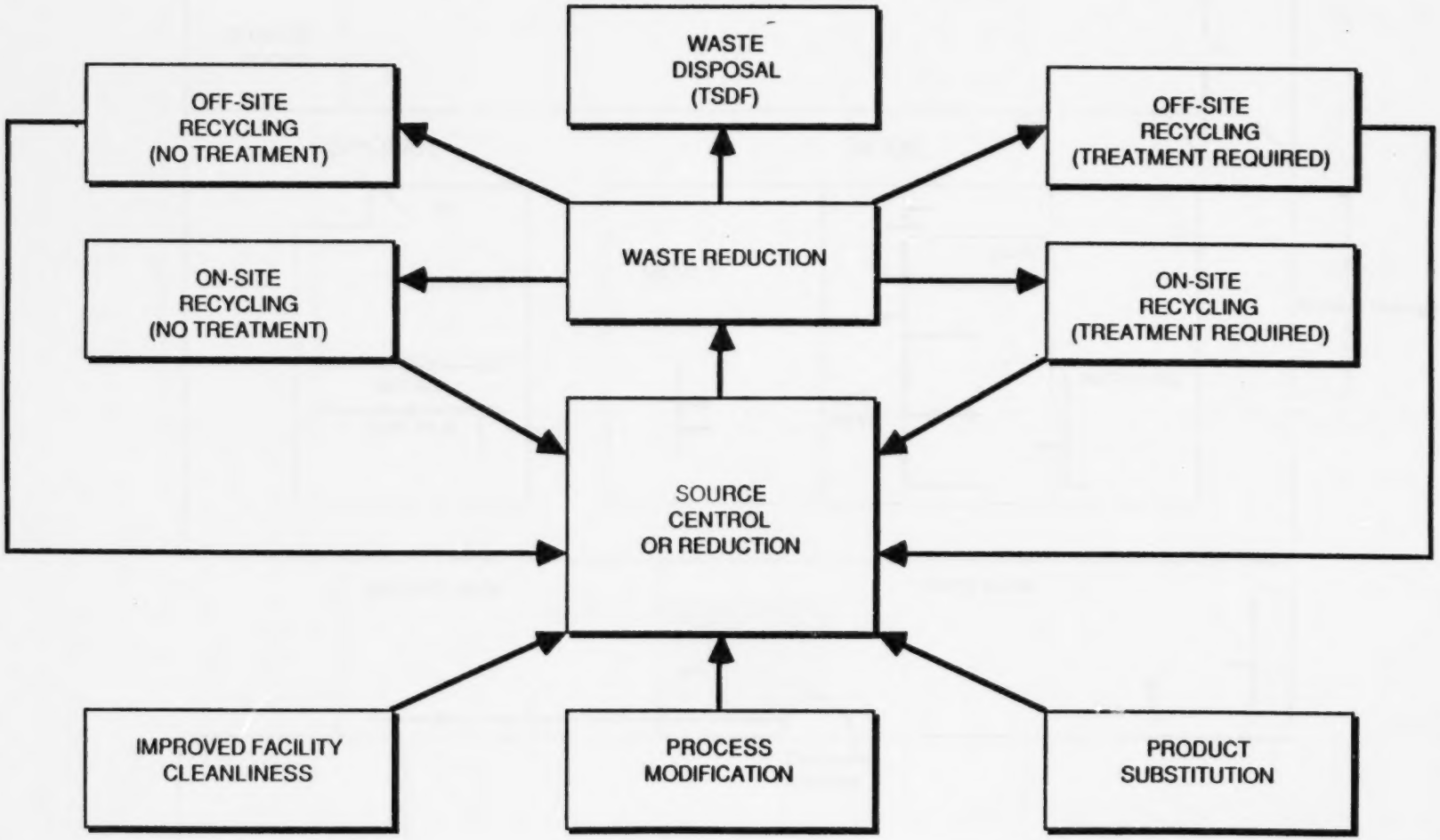
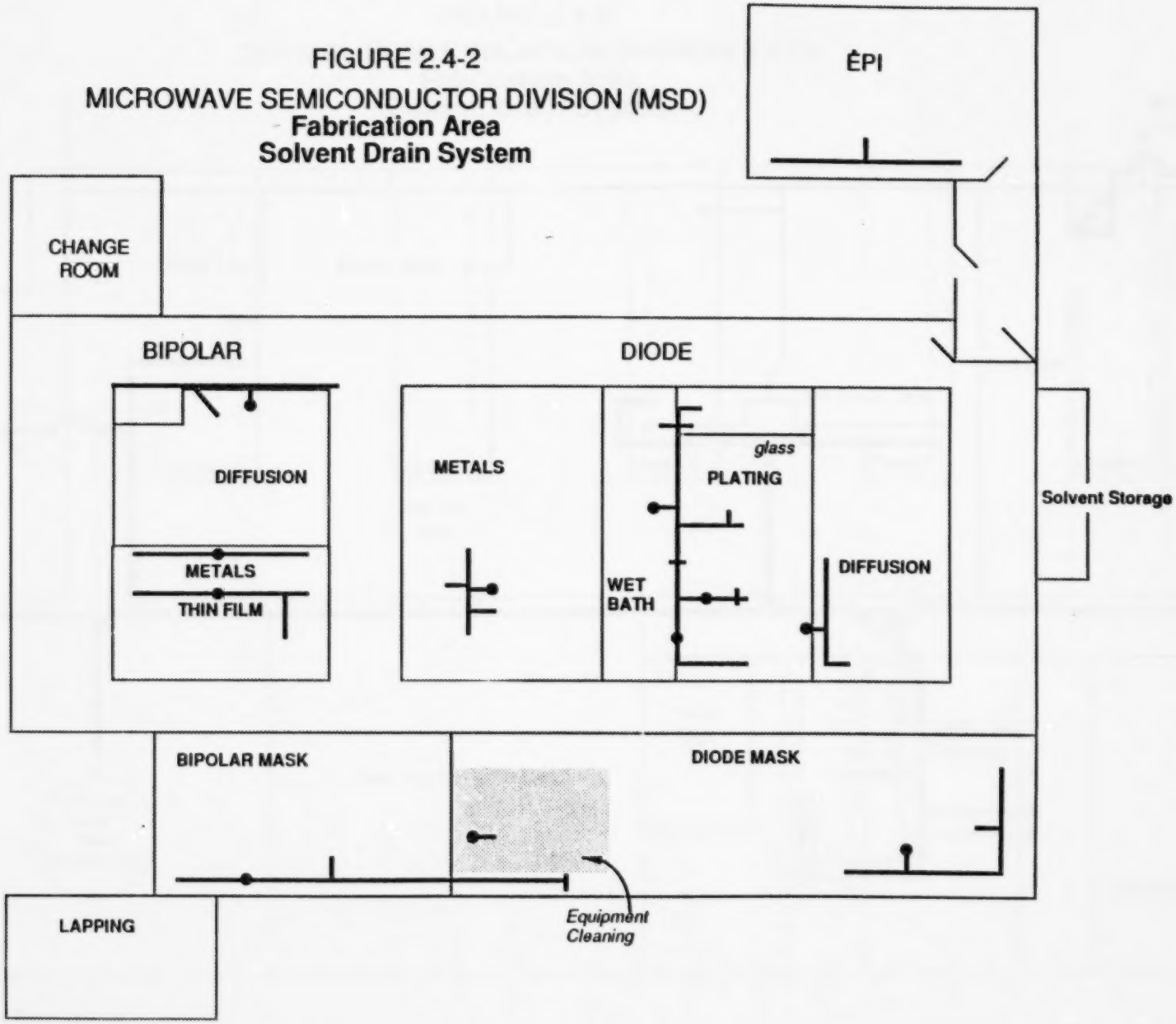


FIGURE 2.4-2

MICROWAVE SEMICONDUCTOR DIVISION (MSD)

Fabrication Area

Solvent Drain System



— Solvent Drain System 1

FIGURE 2.4-3

OPTICAL COMMUNICATION DIVISION (OCD)

Fabrication Area

Solvent Drain System

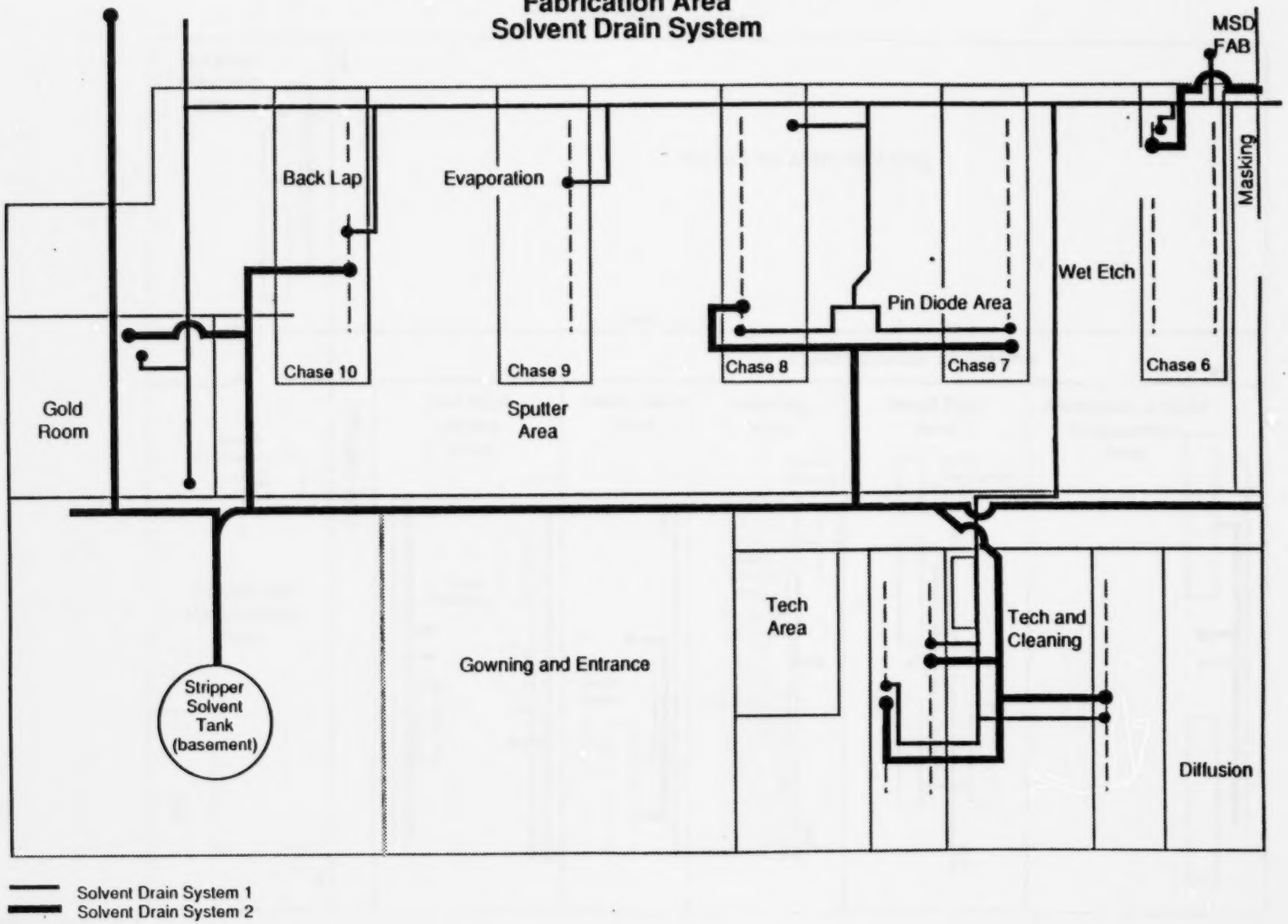
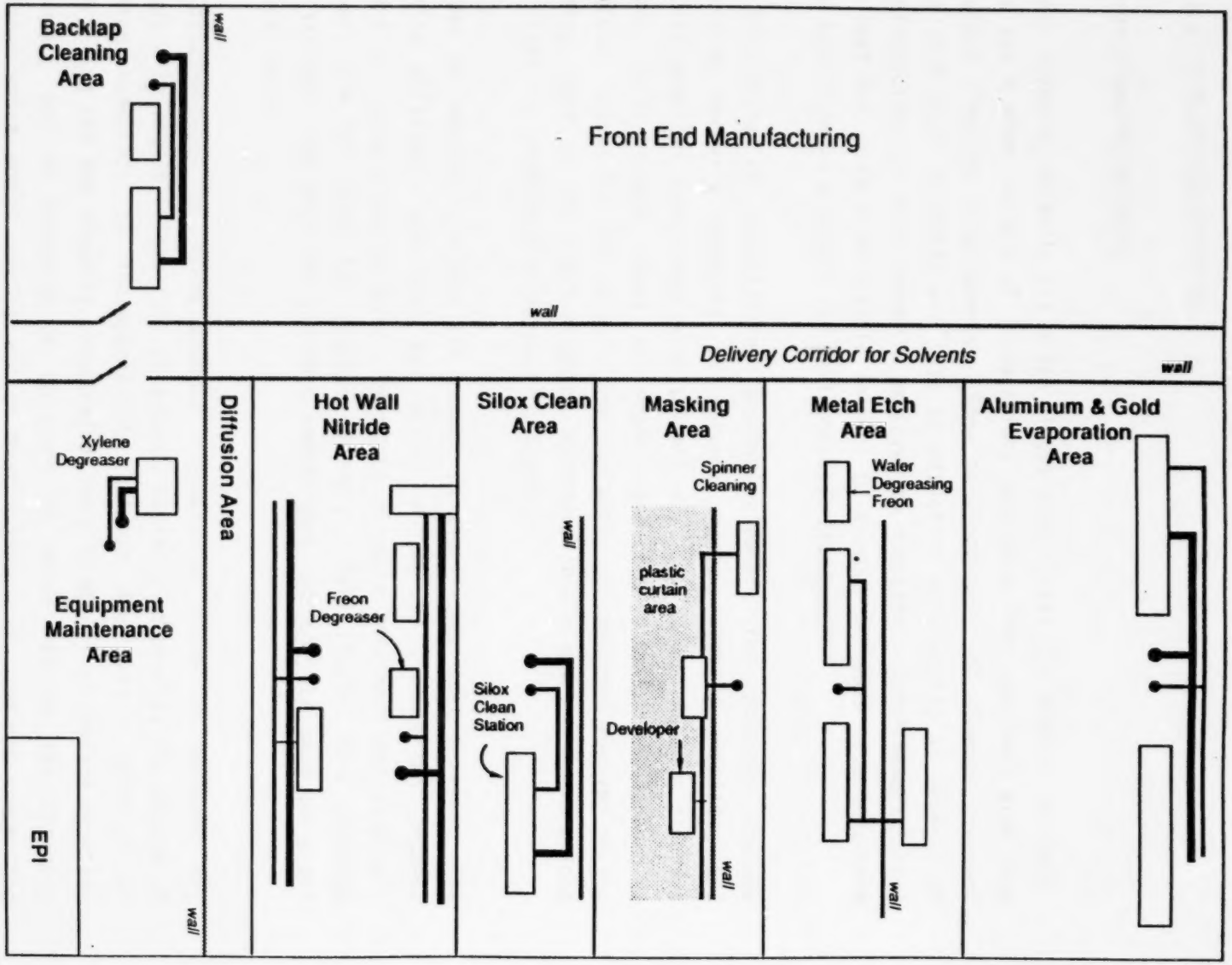


FIGURE 2.4-4

OPTOELECTRONICS DIVISION (OED)

Fabrication Area

Solvent Drain System



Solvent Drain System 1

Solvent Drain System 2

2.4.1.2 Solvent Substitution

Aqueous Cleaning Solvents

Aqueous cleaning solvents are often viable substitutes for organic solvents. There are a wide variety of formulations available that can deal with many different cleaning requirements. Some manufacturers of aqueous cleaners claim that their products are just as effective at cleaning as several of the halogenated solvents commonly employed by industry. These manufacturers feel that the shift from organic solvent to aqueous solvents is a long-term trend both from an economic and environmental standpoint.[1]

The advantages of substituting aqueous cleaners for solvents include minimizing worker's exposure to solvent vapors, reduced liability and disposal problems associated with solvent use, and cost. Aqueous cleaners do not emit harmful fumes or vapors and are usually biodegradable. Therefore, except for the organic and inorganic contaminants removed during cleaning, most of the spent cleaning solutions should not represent a long term liability problem with respect to disposal.

The use of aqueous cleaners can result in significant cost savings. The cleaning efficiency and cost per gallon of aqueous cleaner and organic solvent are roughly equivalent. The costs of waste treatment and disposal, however, are far lower for aqueous cleaners. Case studies have reported such savings, but detailed economic comparisons can only be made on a per facility basis.

The disadvantages of using aqueous cleaners in place of solvents may include: 1) possible inability of aqueous cleaners to provide the degree of cleaning required; 2) incompatibility between the part's material of construction and the cleaning solution; 3) need to modify or replace existing equipment; and 4) presence of moisture on parts leaving the cleaning operation which would require air or heat drying. If problems concerning cleaniness or compatibility arise, then the use of aqueous cleaners may be ruled out if no suitable formulations can be found. Problems related to

very effective in waste minimization. As the cost of digital electronic controls declines further and their reliability is established throughout the industry, their use is expected to increase. Automated systems can reduce the generation of off-specification batches or products in addition to routine clean-up requirements. Computerized process control systems applicable to complex formula-based manufacturing processes such as paint or agricultural chemicals formulation have already been successful and has been proven highly economical. Application to the microelectronics industry should be as viable.

Efficient clean-up methods can minimize the solvent consumption for a given cleaning operation and thus decrease the waste quantity. When solvent-based cleaning is employed, preference should be given to "flow-over" methods which require less solvent than "fill-and-empty" methods. Consideration should also be given to the use of repeated small volume rinsing instead of single large volume rinsing.

2.4.2 Solvent Recycling Processes

A summary of techniques that can be used to purify or concentrate solvents is presented in Table 2.4-1. Dilute aqueous streams containing small concentrations of organic solvents are usually treated prior to discharge to a sewer or a body of water. Solvent recovery is a secondary consideration because of the small quantities of solvent that can be recovered. If recovery is planned, solvent-rich residuals from wastewater treatment (such as carbon adsorption[6] or steam stripping) usually require additional processing such as drying or azeotropic distillation. Concentrated solvent wastes are more frequently recycled. The techniques applicable to the concentrated wastes found at Hewlett Packard are discussed below.

2.4.2.1 Direct Reuse

After solvent recovery and some limited treatment, reuse of solvents in the process should be studied and evaluated. Reuse of used solvent can reduce or eliminate wastes and result in cost savings associated with a decrease in raw material consumption. The solvent from the cleaning can be reused in the next batch formulation, or to make a low grade product.

TABLE 2.4-1

COMMON SOLVENT RECYCLING PROCESSES*

TECHNIQUE	USUAL APPLICATION	
	Concentrated Solvent Waste	Dilute Aqueous Waste
1. Direct Reuse	X	
2. Air Stripping		X
3. Steam Stripping	X	X
4. Liquid-Liquid Extraction	X	X
5. Distillation	X	
6. Evaporation	X	
7. Carbon Adsorption		X
8. Specify Gravity Separation	X	X
9. Centrifugation	X	
10. Dissolved Air Flotation		X

*Guide to Solvent Waste Alternatives, Final Report, California DHS, 1986.

The use of cleaning solvent wastes in the formulation of subsequent batches is practiced to some extent in the paint and agricultural chemicals formulation industries. If a facility employs a large variety of solvents in the batch formulations, the cleaning solutions must be segregated in separate tanks in order to reuse solvent-laden cleaning wastes. This may prove to be expensive.

The Guide to Solvent Waste Reduction Alternatives[1] presents many examples of successful solvent waste reduction due to re-use. Three examples are presented below.

In one east-coast paint manufacturing plant, the waste solvent from each solvent-based paint batch is separately collected and stored. When the same type of paint is produced, waste solvent from the previous cleaning operation is used in place of virgin solvent. By implementing this measure, waste solvent was reduced by over 24,000 gallons per year or 98.4 percent. The same technique is followed for water-based latex paint production processes.

Similar measures followed in another company that uses toluene to clean ink from the printing press, and runoff toluene is collected as waste. This company has nearly eliminated its toluene waste by segregating cleanup toluene according to the color and type of ink cleaned and then reusing the collected wastes to thin future batches of the same ink. The procedure has no effect on product quality and has resulted in almost 100 percent reuse of the toluene solvent.

A third company initiated the practice of segregating spent chlorinated and non-chlorinated solvents used in the formulation of agricultural chemicals. This practice allowed the reuse of each type of solvent and contributed to a substantial decrease in virgin solvent purchase costs as well as solvent waste disposal costs.

2.4.2.2 Air Stripping

Water in an organic solvent waste mixture not only increases the volume and disposal or recycling costs of solvent wastes but also may cause the

2.4.2.4 Distillation/Evaporation

Distillation is the oldest and most popular solvent recovery technique.[6,8] It relies on the difference in volatility between the solvent and the impurities present in the mixture. There are two primary types of distillation: batch and continuous. A batch process, also known as differential, Raleigh, or pot distillation, consists of placing a fixed amount of solvent waste inside a heated evaporation chamber and applying heat with simultaneous withdrawal and condensation of the overhead vapor. As solvent is depleted from the batch inside the pot, the mixture boiling temperature and the partial pressure of high boiling impurities rise. The process is terminated when the impurity level in distillate becomes prohibitive, when the temperature exceeds the limit set by thermal stability of waste constituents and/or materials of construction, or when the viscosity of the residual is increased beyond the range allowing for efficient heat transfer or flow.

In solvent recycling, batch distillation most commonly uses a single equilibrium stage (i.e., there are no packed sections or trays present). Refluxed multistaged batch distillation can be used for fractionation, but the applications are rare. Single stage batch distillation can usually produce acceptable purity (greater than 95 percent), especially if the process is carried out slowly and the components' vapor pressures differ widely.

Continuous multistage distillation, often called fractional distillation, is commonly applied when the following requirements are present:

- o High degree of distillate purity;
- o Volatility differences are small; and
- o Amounts are large.

Distillation is carried out in a column equipped with trays or packing to facilitate maximum contact between liquid and vapor phases. Liquid is introduced continuously into the column with part of the condensed distillate (reflux) introduced at the top. Downward moving liquid is contacted with the upward moving vapor. The vapor becomes progressively

bottoms stream is excessive, special evaporator designs such as agitated film or drum dryer are employed for secondary recovery of solvents from the highly viscous bottom streams.

In a few cases, ability to drain the bottom stream is not a consideration because a disposable plastic liner is used for the boiling chamber in the design of some pot distillation systems. The liners are removed after each cycle. A similar principle is used in applications involving removable pans or where drum containers are used directly as a boiling chamber. Table 2.4-2 contains brief information on a few small stills suitable for on-site recycling.[1] Figures 2.4-5 and 2.4-6 depict a typical small evaporator and distillation recovery still.

Evaporation is a process often used on solvents containing solids or bottoms from distillation units. In a turbulent film evaporator, also called a scraped- or wiped-film evaporator (Figure 2.4-5)[8], a set of rotating blades spreads the waste in a thin film against the heated wall of the cylindrical vessel. The solvent mixture is continually moved against the heated wall of the unit thus maintaining a high degree of heat transfer. Heavy solids and sludges eventually make their way to the bottom of the vessel and are collected.

Solvent vapors exit the top of the unit where they are condensed and further treated if required. Film evaporation can be used to reclaim solvent from heat sensitive viscous wastes including solvent/resin mixtures. It is best suited for low-boiling solvents without abrasive solids.

Single Stage Batch Distillation Equipment

Most small distillation systems are designed as single stage batch stills, ranging from 0.8 to 1,000 gallons batch capacity. Some manufacturers can also provide semi-continuous operating units where the bottoms are not removed continuously but are accumulated during operation and removed periodically. Continuous multistage refluxed distillation systems are usually custom designed based on standardized components and are available

TABLE 2.4-2

SOLVENT RECOVERY STILLS

Manufacturer	Acra Electrical 3801 N. 25th Ave. Schiller Park, IL 60176	Finish Engineering Inc. 921 Green Garden Erie, PA 16501	Hoyt Corp. Westport, MA	Unique Industries, Inc. 1154 Shelton St. Sun Valley, CA 91353	Recyclene Products Inc. 405 Eccles Ave. San Francisco CA 94088	Recyclene	Recyclene
Model	SD-15	LS-JR	ERB	110D-10RW	RS-20	RS-35	RX-35
Solvent boiling range, °F		100-320	below 330		<400	<400	<400
Feed capacity, gal	5	3-5		25	20	35	35
Typical Purity of Product					99	99	99
Typical Yield, %	85	80-95	below 98		95	95	95
Operating time, hr	1.5	8					
Cold start heat-up time, hr	1.84				1.5	1.5	1.5
Distillation rate, gph			4-8	12	3-12*	5-18*	10-37*
Utilities			Air-2SCFM				
Voltage	115/230	110/220	220	240	240	240	240
Phase		1	1	3	1	1	3
Power rating kW	3.66	0.5	5	4.5	3.3	5.0	9.9
Cooling water consumption gal/hr	73	7.5-15	120	186	40	75	75
Material of construction		S.S.	S.S.	heavy gauges	SS	SS	SS
Equipment dimensions in.	21 dia. 27 ht	27x20x19	30x30x92	38x56x59	44x31x44	51x52x51	51x52x51
Weight, lbs	85	150	775		440	804	872
Type of cooling	water	water	water	water	Water	water	water
Type of heating		electric	thermal oil	electric	electric & heat transfer fluid	electric & heat transfluid	electric & heat transfluid
Control features	thermostat	thermostat	programmable controls	level controls	thermostat	thermostat autofill system	thermostat auotfill system
Options		explosion-proof electricals					
F.O.B. Cost, $	775	2,995	14,500	5,270	11,000	16,400 21,000 w/autofill	21,200 25,800 w/autofill
Solvents Recovered	TCE, 1-1-1 TCE .PCE, etc	Alcohols, aromatics, chlorinated solvents, aliphatics ketones	Hazardous waste solvents	Chlorinated, fluorinated	Methylene chloride, Freon TF, Acetone Methanol, 1-1-1 TCA, IPA, Toluene, N-butyl-Acetate, Xylene, Mineral Spirits (Stoddard Solvent) * - Varies with Solvent	Same as RS-20	Same as RS-20

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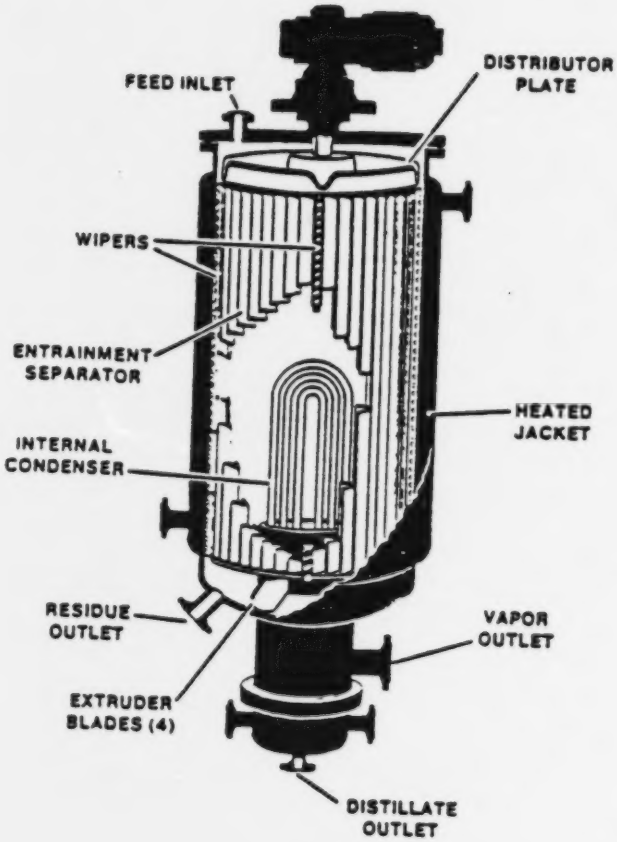


FIGURE 2.4-5

Wiped Film Evaporator

Source: Pfaudler Company

1. Shell and Tube Condenser
2. Solvent Liner (Nylon or Teflon)
3. Teflon Gasket Seal
4. Dirty Solvent Drum
5. Oil-Immersed Rapid Cooling System
6. Stainless Steel Double Boiler
7. Oil-Immersed Resistance Heater
8. Air-Operated Pump for Autofill
9. Pneumatic Lid Foot Pedal
10. Multiple System Thermostats (Explosion-proof):
    a. Vapor
    b. Condenser
    c. Boiler
    d. Lid Interlock
    e. Safety
11. Main Contactor Box
12. Clean Solvent Drum
13. On/Off Controls and "Cycle On" Light Panel
14. Breather Vent
15. Vapor Temperature Gauge
16. Oil Temperature Gauge
17. Water Flow Meter

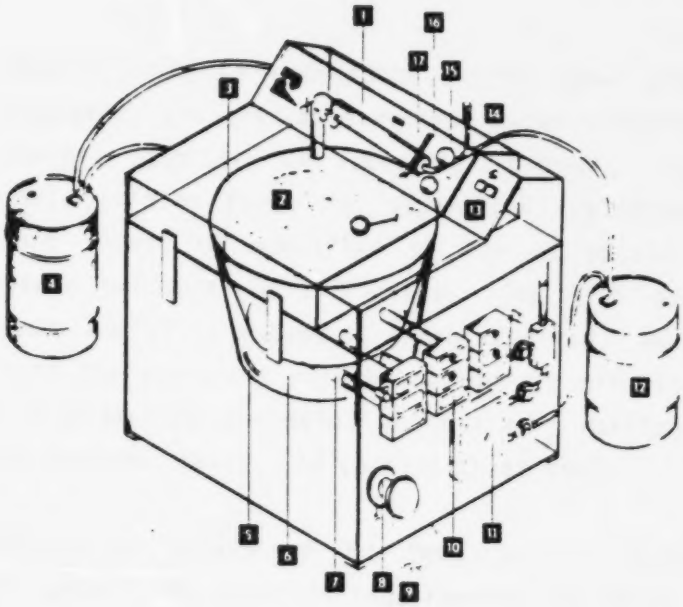


FIGURE 2.4-6

Distillation Solvent Recovery System

from a smaller number of suppliers. These units range from 1 to 1,440 gallons per hour capacity based on the feedrate.

There are many factors and options to consider when specifying solvent recovery distillation equipment[1,8]. These are summarized in Figure 2.4-7. They are intended to guide the buyer through the major equipment options and choices available. Key features of distillation equipment selection are discussed below.

Stream characteristics list the quantities, compositions and properties of the system feed, distillate, and bottoms streams as required by the buyer. Hourly mass flowrate (lbs/hr) for each stream should be provided to the vendor based on the maximum still throughput expected and not as an averaged value. Feed discharge stream purity requirements should be based on laboratory analyses where possible.

System pressure specification is a function of the vapor pressures of the solvents to be separated, the available cooling water temperature, and the volatility and thermal stability of impurities present. To provide the largest thermodynamic driving force for separation (relative volatility), the system pressure should be specified as low as possible. For most solvents, atmospheric pressure is sufficient. For high boiling species (boiling points above 400°F), a vacuum is often required. When a vacuum is used, air leaks into the equipment must be avoided to minimize the risk of fire, explosion, or premature corrosion or fouling. Particular attention must be paid to the gaskets, seals, and packing types used.

Operating temperature is determined by the specific system operating pressure indicated above. The capacity requirements are based on the waste generation rate, stream characteristics, product purity requirements, and plant operation schedules. The mode of operation may be batch or continuous for the same reasons. The solvent waste may be allowed to accumulate for a period of time before distillation to recover pure solvent. The overall facility's schedule of operation usually should determine the frequency of operation of the unit. For low feed rates, batch operation is preferred with reflux ratio and the number of theoretical stages determined by the

Figure 2.4-7

SOLVENT RECOVERY STILL DATA SHEET

SOLVENT RECOVERY STILL DATASHEET	PROJECT NO.	SPEC. NO.
Service	Item(s) Tag No.	
For	By	Date	Rev. No.
Site	Approval by	Date
Manufacturer	Size and Model	
	Serial No.	
Bench/Pilot Test Required Yes ☐ No ☐	No. Units Required	

STREAM CHARACTERISTICS

Attribute	Feed		Distillate		Bottoms
	Dirty Solvent	Stripping Stream	Solvent Phase	Water Phase	
Flowrate, lb/hr					
Component, weight %					
1.					
2.					
3.					
4.					
5.					
6.					
7.					
8.					
9.					
10.					
Temp., °F					
Pressure, psig					
Density, lb/cu. ft					
Viscosity, cP					
Thermal Cond.,Btu/hr-ft-°F					
Latent Heat, Btu/lb					
Spec. Heat, Btu/lb-°F					
Boiling Range, °F					
Toxic (Y/N)					
Corrosive (Y/N)					
Ignitable (Y/N)					
Max. Stable Temp.,°F					
Steam Degradable (Y/N)					
Other					

Courtesy of *Guide to Solvent Waste Alternatives - Final Report*, California DHS, 1986.

Figure 2.4-7 (Continued)

SOLVENT RECOVERY STILL DATA SHEET

CAPACITY AND OPERATION REQUIREMENTS

Dirty Solvent Load : Lb/Shift Shift/Day Days/Week

Mode Of Operation : Batch (Rayleigh) ☐ Continuous ☐ Other(Explain) ☐

Still Capacity : Lb/Hr Feed ☐ Product ☐

Turndown Ratio :

No. Of Stages : Theoretical Actual ΔP, In.WC.

Trays ☐ Type Spacing ΔP, In.WC.

Packing ☐ Type HETP, Inches ΔP, In.WC.

Reflux Ratio Design Range

HEATING MODE	Direct Steam Inj. ☐	Shell & Tube Reboiler ☐	
	Insert Tube Bundle ☐	Jacket ☐	Coil ☐
	Electric ☐	Other (Explain) ☐	

AVAILABLE UTILITIES / CONSUMPTION RATES

Steam : Sat. ☐ Pressure Level(s), PSIG : Flow, Lb/Hr

Supht. ☐ Press.,PSIG/Temp. °F : Flow, Lb/Hr

Vacuum : mm Hg Abs. Flow, ACFM

Plant Air, PSIG , SCFM Instr. Air, PSIG , SCFM

Cooling Water : Temp. In/Out, °F GPM

Electric Power : Volts Phase Hz KW

Heating/Cooling Media :

SPACE / INSTALLATION / TEST REQUIREMENTS

Length Height Width

Weight, Lbs Empty Operating

Stationary ☐ Moveable ☐

Foundations Required Yes ☐ No ☐

Field Assembly Required Yes ☐ No ☐ No. of Delivered Modules

Estimated Assembly Labor, Mhrs

Insulation Shop ☐ Field ☐

Painting Shop ☐ Field ☐

Performance Test Witnessed ☐ Nonwitnessed ☐

Hydrostatic Test Witnessed ☐ Nonwitnessed ☐

Shop Inspection Yes ☐ No ☐

Courtesy of *Guide to Solvent Waste Alternatives - Final Report*, California DHS, 1986.

Figure 2.4-7 (Continued)

SOLVENT RECOVERY STILL DATA SHEET

INSTRUMENTATION

Piping and Instrumentation Diagram Provided Yes ☐ No ☐

Conceptual Control Schematic Provided Yes ☐ No ☐

Instrumentation Requirements Mfg Standard Acceptable ☐

Custom Requirements ☐

Automatic Control Options :

Feed Flowrate ☐ Bottoms Flowrate ☐ Condenser Temp. : Inlet ☐ Outlet ☐

Reboiler/Still Liquid Level ☐ Receiver Liquid Level ☐

Still Pressure ☐ Reflux Ratio ☐

Monitoring Options (A - Alarm ; I - Indicator; R - Recorder ; M - Multiplex)

	Liq. Level	Pressure	Temp.	Flow	Composit.
Solvent Feed					
Steam Feed					
Reboiler/Still					
Receiver					
Separator					
Condenser Inlet					
Condenser Outlet					
Clg. Wtr. Inlet					
Clg. Wtr. Outlet					
Bottoms					
Feed Tank					
Bottoms Tank					

Control Panel Local ☐ Remote ☐

SAFETY FEATURES

Automatic Unit Shutdown Due To :

CW Failure ☐ Low Level ☐ Other ☐

Bottoms Temperature ☐ Pressure ☐ Feed Interrupt ☐

Overpressure Protection :

Rupture Disk(s) ☐ Relief Valve(s) ☐ Other ☐

Explosion - Proof Electricals Yes ☐ No ☐

Grounding Protection ☐

Courtesy of *Guide to Solvent Waste Alternatives - Final Report*, California DHS, 1986.

Figure 2.4-7 (Continued)

SOLVENT RECOVERY STILL DATA SHEET

EQUIPMENT TO BE SUPPLIED	
FEED	1. Feed Transfer Pump ☐ 2. Feed Tank ☐ Gravity Flow ☐
	3. Feed Charge Pump ☐ 4. Filter(s) ☐ 5. Strainer(s) ☐
	6. Feed Preheater ☐
STILL	7. Boiling Chamber ☐ 8. Column ☐
	9. Column Internals ☐ 10. Reflux Head ☐
DISTILLATE	11. Condenser ☐ 12. Receiver ☐ 13.Coalescer/Separator ☐
	14. Reflux Pump ☐ 15. Product Pump ☐ 16. Product Tank ☐
BOTTOMS	17. Reboiler ☐ Type :
	18. Bottoms Pump ☐ 19. Bottoms Tank ☐
	Removal Mode : 19. Pan ☐ 20. Liner Bag ☐ 21. Gravity Flow ☐
AUXILIARY EQUIPMENT	22. Chiller ☐ 23. Cooling Tower ☐ 24. Boiler ☐
	25. Vacuum Generator ☐

COMPONENT DESIGN PARAMETERS

PARAMETER	Package Component Number (from above)									
Pump GPM/TDH, ft.										
Tank Capacity, gal.										
Dimensions /Size										
Duty, BTU/ hr										
Heat Transfer Area, sq. ft.										
TEMA Type										
Mat'l. of Construction										
Shell										
Tube										
Impeller										
Casing										
Liner										
Gaskets										
Corrosion Allowance										
Design P/T (PSIG/°F)										
Design Code										

Courtesy of *Guide to Solvent Waste Alternatives - Final Report*, California DHS, 1986.

relative volatilities of the species and the specified product purity needed. A detailed description of the design and operation principles of distillation columns can be found in many standard texts.[8,14,19]

The choice of the heating mode is determined by the available utilities, preference of the operator, and the characteristics of the bottom stream. If the bottoms are very viscous, better heat transfer can be obtained by using direct steam injection. Direct stream injection can be used only if the product is not steam degradable and if water is a tolerable impurity in the recovered solvent. The aqueous wastestream that is generated by this process may need treatment before disposal to the sewer.

Equipment space availability, as well as installation and test requirements should include consideration for the need for weather-proof equipment and whether pre-shipment performance tests are required. Close attention must be paid to the location of the installed still in the facility. A well ventillated, easily accessible area away from possible ignition sources, but in close proximity to feed sources is preferable. A close examination of fire codes such as the Uniform Building Codes, National Electric Code (NEC), National Fire Protection Association (NFPA) and Occupational Safety and Health (OSHA) is recommended.

The automatic operation control options consist of flow, level, temperature, and pressure regulation. The heat input rate can be fixed or controlled in a modulating or on-off fashion, by bottoms or vapor temperature, or by bottoms liquid level. Heat input can be independently interrupted by a low liquid level, high temperature condition in the pot, or loss of cooling water to the condenser. Low liquid level shutdown can prevent severe fouling of unsubmerged heating surfaces. Cooling water flow can be modulated by the condensed distillate temperature controller. When stringent product purity requirements exist, or when the operation is continuous, a higher level of control sophistication is required.

Safety features such as explosion proof electrical connections and grounding protection are required when flammable solvents are handled. Relief valves

waste exchanges. Waste exchanges are private or government-funded organizations that facilitate recycling transactions by identifying the supply and demand for various wastes.

There are two types of waste exchanges: information exchanges and material exchanges. Information exchanges act as clearing houses for information on waste demand and supply. Material exchanges take temporary physical possession of the waste and may initiate or actively participate in the actual transfer of wastes to users. Supplementing the activities of these two types of waste exchanges are waste brokers. Brokers are individuals or firms which, for a fee, locate processors, sellers, or companies to use the recyclable materials. The broker does not take physical possession of the material.

In California, an information exchange is operated by the California Waste Exchange (CWE).[21] It is a program administered by the Toxic Substances Control Division of the Department of Health Services. CWE publishes a directory of industrial recyclers and a quarterly newsletter and catalog. The newsletter documents recent developments in the area of hazardous wastes (i.e., laws, regulations, technology). The catalog lists wastes requested and wastes available. Through this service, industries locate parties interested in receiving their wastes. The parties in the catalog are identified only by a box number, a procedure much the same as that used in classified ads. This system ensures a necessary degree of confidentiality because some companies fear that an analysis of their wastes could reveal proprietary information about their manufacturing process.

Wastes currently recycled through waste exchanges include acids, alkalis, other inorganic chemicals, organics and solvents, and metals and metal sludges. Of these wastes, organic solvents and metal wastes are most frequently listed by waste exchanges. These materials have a high recovery value. Of the total wastes listed via exchanges, approximately 20 to 30 percent are exchanged. Table 2.4-3 indicates the current solvents most commonly recycled by the California Waste Exchange.

TABLE 2.4-3

CALIFORNIA WASTE EXCHANGE
SOLVENTS MOST COMMONLY RECYCLED

1,1,1 trichloroethane (TCA)
tetrachloroethylene (TCE)
trichlorotrifluoroethane (Freon)
methylene chloride
lacquer thinner
mixed solvents (oxygenated and aromatic hydrocarbons)
naphthas
xylenes
toluene
methyl ethyl ketone (MEK)
acetone
isopropyl alcohol
methyl alcohol
benzene
mineral spirits (petroleum distillate)

2.4.3 Solvent Disposal -Incineration

Because incineration is currently the most common process employed for permanent organic solvent disposal in California[1], discussion of off-site disposal will be limited to incineration types and operating characteristics of each. Due to the high cost encountered for solvent incineration, this method is usually not preferred from an economic and environmental standpoint if recycling processes can be economically justified.

Incinerators can be used to destroy solvent waste by using the waste as a supplement to fossil fuel. It was reported that almost 5,000 industrial boilers in the United States burn waste-derived secondary fuels. The major concerns of incinerating the solvents are the heating value of the fuel mixture and the solids in the waste solvent. The variation in the composition and the strength of the solvents may affect the efficiency of the combustion chambers. The solids in the solvents may plug the burner nozzles, build-up deposits in the units, or cause an increase in the particulate emissions. Also, excess chlorine in the waste solvent may corrode the refractory and metal parts. There are several types of incineration systems that are available on the market. The major systems are summarized below. Presently many new systems have been developed in incineration technology. The systems showing prominance for future application are: Molten Salt Incinerators; Wet-Air Oxidation; Circulating Bed Combustion and High Temperature Fluid Wall Incinerators.

Rotary Kilns

The major component of the rotary kiln is a cylindrical, refractory-lined chamber. The waste mixes in the chamber by the rotation and the tilt induces the solids to flow towards the outlet where they are continuously removed. Gaseous combustion products formed during combustion pass through an afterburner or a liquid injection system and then through scrubbers. Residence times vary from seconds for gases to hours for solids.[8] Temperatures typically reach 3,000°F. Waste handling capacity ranges from

considerable entrainment of bed particles into the moving stream of gas. The particles are de-entrained in a cyclone and routed back to the bed. Pilot scale tests have shown better than 99.999+ percent destruction efficiency with chlorinated organic solvents.[1]

Multiple Hearth Incineration

Multiple hearth incineration systems usually consist of a refractory lined steel shell, a rotating central shaft, a series of rabble arms with teeth for each hearth, air blower, fuel burners mounted on the walls, ash removal system, and a waste feeding system. It can also be used for liquids by equipping with a liquid waste burner, an after burner and side ports for injection. Waste enters as a sludge at the top and is pushed across the various levels by the rabble arms. As the waste passes to the hearths below, it is incinerated and the ash discharged at the bottom. During the process, waste liquids may be injected through side ports to improve combustion.[8]

Multiple hearth incinerators can be used for incineration of all forms of combustible wastes, including sewage and industrial sludges, tars, solids, gases, and liquid combustible wastes. Highly contaminated solvents and residues from solvent reclamation can be blended together and used as fuel. The major advantages are: residence times are extremely long which leads to efficient destruction of less volatile material; large quantities of water can be evaporated; fuel efficienty is high; and a wide variety of wastes can be handled. Disadvantages include potential hot and cold spots inside the unit which can lead to incomplete combustion and increased maintenance cost due to the moving parts contacting the combustion gases. Multiple hearth incineration is not well-suited for wastes containing fusible ash, wastes requiring high temperatures for destruction, or irregular bulky solids.

Plasma Arc Incineration

Plasma arc incineration utilizes a plasma generator to pyrolize hazardous waste. An intense electrical current is passed through air at low pressure

2.5 EVALUATION OF WASTE REDUCTION PROCESSES

2.5.1 Selection Criteria

Solvent Substitution

Substitution of aqueous solvents for organic solvents is an attractive alternative when practical because it could reduce disposal costs associated with solvent wastes. For example, if low levels of organic contaminants can be achieved, the waste water could be discharged under an existing discharge permit.

The advantages of substituting aqueous solvents for organic solvents include minimizing worker's exposure to solvent vapors, reduced liability and disposal problems associated with solvent use, and cost. Aqueous solvents do not emit harmful fumes or vapors and are usually biodegradable. Therefore, except for the organic and inorganic contaminants removed during cleaning, most of the spent aqueous solvent solutions should not represent a problem with respect to disposal.

The use of aqueous solvents usually provides a cost savings with respect to disposal costs only. The cleaning efficiency (number of parts cleaned per gallon of cleaner) and cost per gallon of aqueous solvent and organic solvent are roughly equivalent. The costs of waste treatment and disposal, however, favor aqueous cleaners. Case studies have reported such savings, but detailed economic comparisons can only be made on a per facility basis.

The disadvantages of using aqueous solvents in place of organic solvents may include: possible inability of aqueous cleaners to provide the degree of cleaning required, incompatibility between the part's material of construction and the cleaning solution, need to modify or replace existing equipment, and presence of moisture on parts leaving the cleaning operation. If problems concerning cleanliness or compatibility arise, then the use of aqueous cleaners may be ruled out if no suitable formulations can be found. Problems related to equipment modification or the unacceptability of wet

machinery but could be substantially increased by reusing the stripper solvents after drying and filtration. This should be possible even though these wafer manufacturing steps require high purity solvents.

Air Stripping

Air stripping is an excellent method for removing very low concentrations of volatile organic compounds from aqueous waste streams. This process is most efficient in the removal of contaminant concentrations on the order of 5 ppm or less. This consideration would probably preclude the use of air stripping for solvent removal except for cases in which very low concentrations are involved.

Liquid-Liquid Extraction

Many valuable organic compounds can be removed from solvent waste streams efficiently by liquid-liquid extraction. However, high costs of the extraction solvent, variability in extraction efficiency and difficulty in separating the extracted solvent from the extracting liquid virtually eliminate this process from consideration.

Distillation/Evaporation

Single stage batch distillation (evaporators) can usually produce purity of a single solvent of greater than 95 percent. The equipment is fairly simple to operate and maintenance efforts and downtime appear to be minimal. The attractively low capital cost of this equipment make such distillation systems worth consideration for all firms that produce more than eight (8) gallons per day of solvent waste. This solvent recovery process appears to have the greatest potential for substantially reducing the solvent wastes at Hewlett Packard via on-site recycling.

Waste Exchange

The California Waste Exchange is currently not utilized at Hewlett Packard's San Jose site because of the mixed solvent stream that results. The

TABLE 2.5-1

SOLVENTS TO BE CONSIDERED FOR ON-SITE RECYCLING PROCESS DESIGN

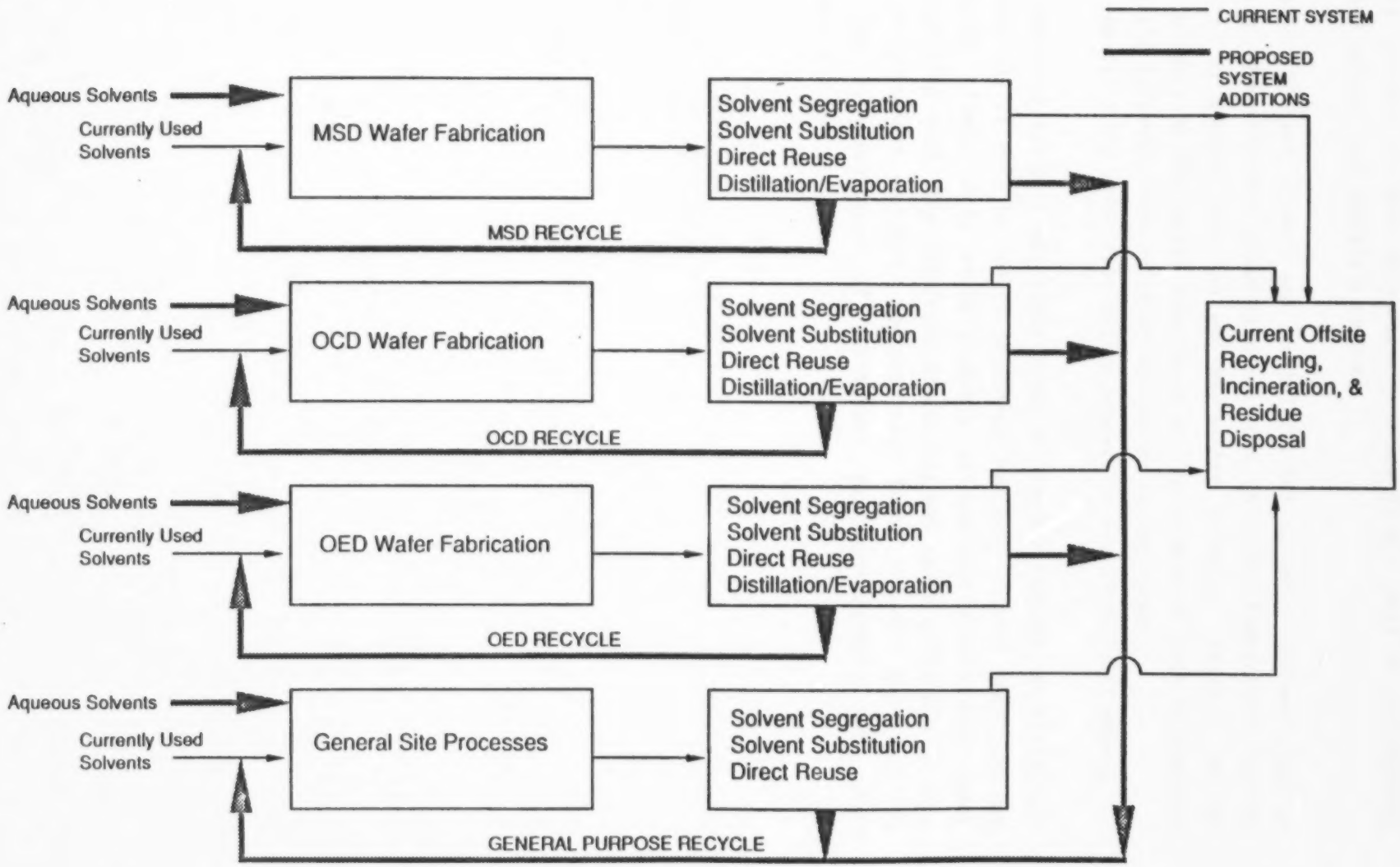
	Solvent	Volume[1] Purchased Annually (gal)	Total Purchase Cost	Disposal[2] Cost	Total Annual Cost to Hewlett Packard
1.	Stripper Solvent	9,542	$178,400	$30,100	$208,500
2.	Isopropyl Alcohol	9,737	$ 42,800	$30,700	$ 73,500
3.	Trichloroethane (TCA)	5,683	$ 48,300	$17,900	$ 66,200
4.	n-Butyl Acetate	1,092	$ 44,800	$ 3,400	$ 48,200
5.	Acetone	3,547	$ 17,700	$11,200	$ 28,900
6.	Freons	610	$ 11,000	$ 1,900	$ 12,900
7.	Methanol	1,437	$ 7,200	$ 4,500	$ 11,700
8.	Xylenes	1,313	$ 5,800	$ 4,100	$ 9,900
	TOTALS	32,961	$356,000	$103,800	$459,800

(1) Includes only the three wafer fabrication areas (approximately 87 percent of facility total of 38,000 gal/yr).

(2) Assumes vapor losses equal addition of water (approximately 15 percent). Assumes disposal costs are equal for each solvent.

Figure 2.5-1

PROPOSED SOLVENT RECYCLING PROCESSES



chemicals in these stripper solvents will allow direct reuse if contaminants (water and solids) are adquately removed.

Halogenated (TCA and freons) and non-halogenated solvents (xylene) used in degreasing, dewaxing and cleaning operations in wafer fabrication may be substituted by aqueous cleaning and degreasing solvents. Because the new aqueous solvents on the market have keyed on replacement of such halogenated and aromatic solvents, this substitution may be accomplished without impacting the wafer fabrication process to any significant degree.

Of the remaining solvents not substituted or thereby reduced, distillation/evaporation stills will be tested to assess how much solvent recycling can be achieved. These units would probably be operated within each wafer fabrication area much like the freon degreasing and reuse units now in use. Because HP personnel currently operate these freon cleaning and recycling stills, the implementation of additional equipment should not incur significant problems.

2.6 ENVIRONMENTAL PERSPECTIVE

2.6.1 Introduction

This section addresses the health and environmental aspects of solvent waste recovery processes. Organic solvents both in liquid and in vapor phase could present a health hazard to humans and environment when they are released into the environment as a consequence of an industrial process.

Health impacts of exposure to organic solvents have been extensively studied by toxicologists. Toxicology is the study of the adverse effects of chemicals on living organisms.[15] The major routes by which toxic agents gain access to the body are through the gastrointestinal tract (ingestion), the lungs (inhalation) and the skin (topical).

One of the typical environmental concerns associated with solvent toxicity is industrial worker exposure to harmful vapors. Considerable effort has gone into both animal and human studies in attempts to determine safe levels of exposure in the work environment. These data have been compiled and evaluated by the American Conference of Government Industrial Hygienists (ACGIH), and published in a yearly document called Threshold Limit Values (TLVs) and Biological Exposure Studies.[5,10] Some TLVs for typical organic solvents used in the electronics industry are presented below:

Acetone	1,780 mg per cubic meter of air
Methanol	260 mg per cubic meter of air
Isopropyl Alcohol	980 mg per cubic meter of air
Trichlonoethane (TCA)	7 mg per cubic meter of air
n-Butyl Acetate	710 mg per cubic meter of air
Xylenes	435 mg per cubic meter of air

It should also be noted that the cumulative effect of exposure to a mixture of vapors may be additive, antagonistic, or potentiating, depending on the mechanism of toxicity. Where two or more chemicals may have similar toxic response (i.e., anesthesia) or have an impact on the same target organ (i.e., liver), the effects can be considered additive.

portation or to treatment, storage, or disposal facilities without obtaining an EPA identification number.

Section 66508.

This section states that a generator can accumulate hazardous waste for 90 days or less without a permit. If a generator plans to store these wastes for more than 90 days, a facility permit has to be obtained unless the Department of Health Services has granted an extension to the 90 day period.

Section 66699.

This section is entitled Persistence and Bioaccumulative Toxic Substances. It specifies limits of Soluble Threshold Limit Concentration (STLC) and Total Threshold Limit Concentrations (TTLC) for chemicals.

If the concentrations are less than the TTLC but more than 10 times the STLC, approval should be obtained from the Department of Health Services to exempt the waste from management as hazardous waste.

Section 66723.

Total Threshold Limit Concentration values for Persistent and Bioaccumulative Toxic Substances in Extremely Hazardous Waste are listed in this section.

Section 66744.

This section informs the generator of hazardous waste to obtain prior written approval from the Department of Health Services for any waste to be classified as a special waste.

Section 66900.

This section lists chemical names and their concentrations regarded as hazardous wastes or restricted hazardous wastes. Liquid wastes containing chemicals listed in this section at concentrations greater than the specified limits are restricted from land disposal.

Figure 2.6-1

WASTE AND UNIT CLASSIFICATIONS USED IN CALIFORNIA

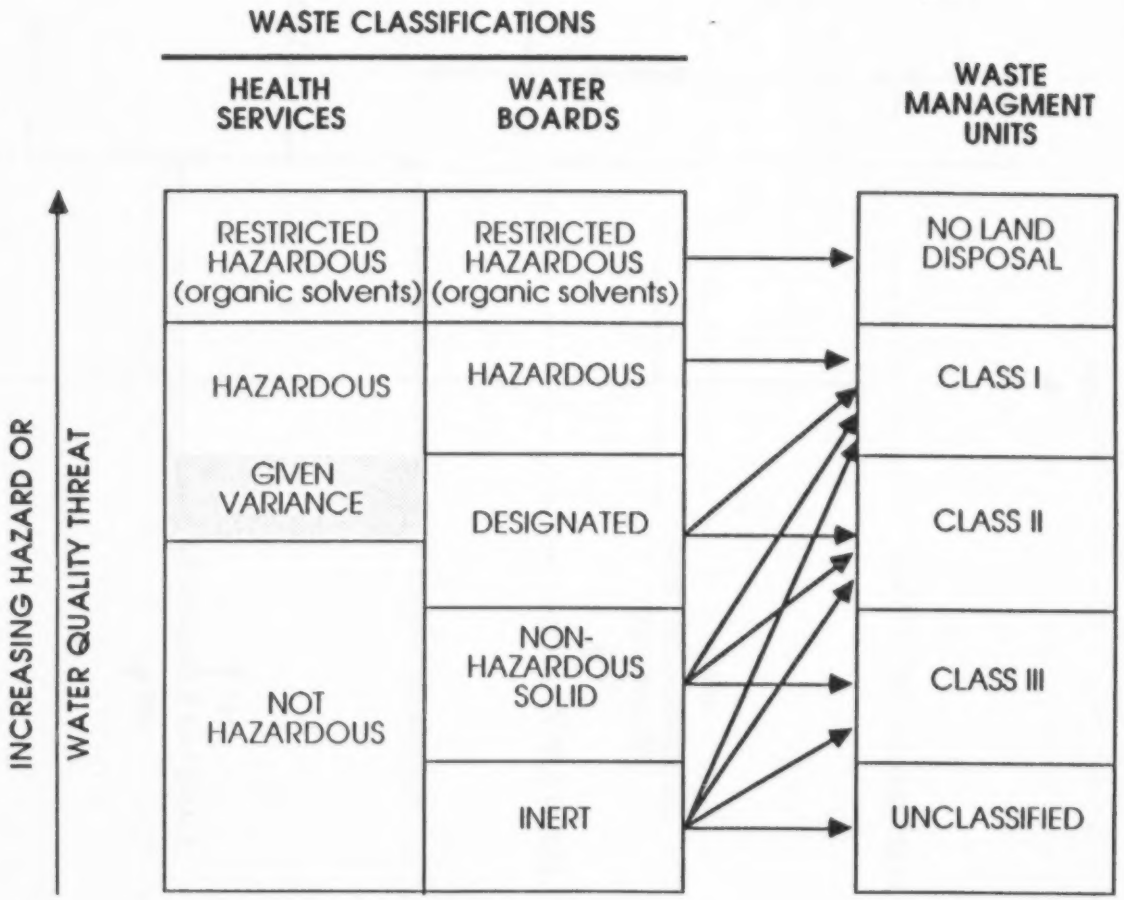
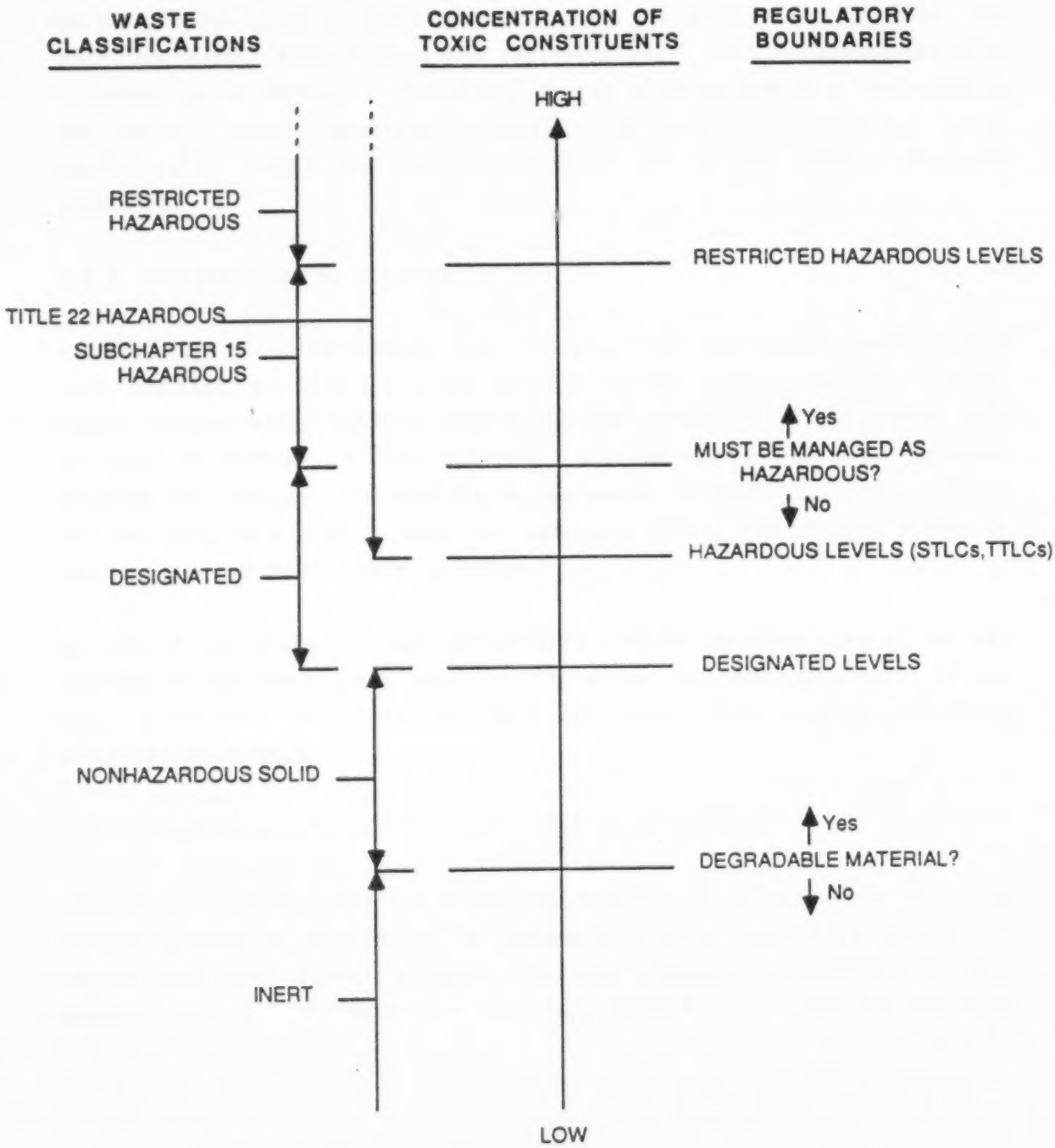


Figure 2.6-2

RELATIONSHIP BETWEEN WASTE CLASSIFICATION AND CONCENTRATIONS OF TOXIC CONSTITUENTS



2.6.2 Reduction of Solvent Waste Volume Generated Statewide

Based on the evaluation of solvent waste reduction processes at Hewlett Packard's San Jose facility, application to any other type of industry generating or using organic solvents appears viable. The techniques and the treatment processes presented are easily available to any industry regardless of solvent volumes involved and appear to be economically justifiable not only from the basis of purchase costs saved and disposal costs saved, but more importantly from a long-term liability basis that is associated with hazardous waste disposal. Therefore, it can be projected that implementing the solvent waste reduction processes and techniques presented would substantially reduce the volume and types of solvent wastes generated statewide.

2.6.3 Acceptability By Industry

Acceptability of solvent waste reduction practices can only be assessed once each manufacturer identifies the solvent volume process sources, solvent types, solvent waste handling piping and the current costs associated with purchase and disposal of their solvents. In other words, the waste reduction programs must appear: 1) possible to implement; 2) economically justifiable for the long term; and 3) must not adversely affect the product volume or quality that the manufacturer produces.

Because of the widespread use of solvents similar to those used at Hewlett Packard in the electronics industry, it can be concluded that most, if not all, electronic microchip manufacturers will find on-site recycling processes acceptable.

2.6.4 Transferability to Other Industries

This study indicates that the technology transfer of solvent waste recycling processes would be much easier to implement in other industries that do not demand such high purity solvents and manufacturing environments as does Hewlett Packard. The recycling processes identified are not new nor have

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